

Cooperation and Competition on the Path to Fusion Energy

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Cooperation and Competition on the Path to Fusion Energy

A Report Prepared by the
Committee on International Cooperation in Magnetic Fusion
Energy Engineering Board
Commission on Engineering and Technical Systems
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PREFACE

Because the magnetic fusion process holds unique promise as a long-term energy source or as a source of neutrons, efforts have persisted for many years to solve its challenging scientific and engineering problems. Major programs have been undertaken in the United States, Europe, Japan, and the Soviet Union. As the size and complexity of the experimental devices have grown, international cooperation has occurred in order to produce earlier results, to share risk, to minimize investment, or to acquire skills. Faced with even more demanding future program requirements, officials of the U.S. Department of Energy are considering whether greater levels of international cooperation offer benefits. The Committee on International Cooperation in Magnetic Fusion was appointed by the Commission on Engineering and Technical Systems of the National Research Council to address this question for the Department of Energy. The committee functioned under the guidance of the Energy Engineering Board of the Commission.

The purpose of the study is to recommend a worthwhile course of action in international cooperation, as measured by the criteria of acceptable policy, technical merit, and practical workability.

New and substantial undertakings in international cooperation will depend in a complex and interrelated way on the perceptions of persons at the technical, political, and industrial levels. Accordingly, the committee obtained the viewpoints of such persons by conducting two workshops in the United States and by meeting with officials in the European Community and in Japan. During these meetings, instances of international cooperation in both fusion and other technologies were examined for the lessons they might contain. Various incentives and constraints to cooperation exist, which, taken together, will determine the policies of each of the three main free-world programs. There are also many technical needs and opportunities, ranging from minor participation in supporting experiments to joint investment in costly facilities for generic technology development and the sequencing, or indeed the collaborative construction and operation, of a series of major experimental fusion devices. There are also many

types of agreement and details of implementation that may be devised or adapted to carry out cooperation toward joint objectives. All these considerations are discussed here.

No attempt has been made to pass judgment on the various technical approaches being undertaken. However, we have tried diligently to reflect accurately the attitudes and concerns expressed during our meeting and visits.

In looking back over our work, I believe that we have established the need for the United States to articulate its goals, programs, schedules, and commitment more clearly as a prerequisite for the negotiation of cooperative activities. I believe also that we have set forth a number of conditions that should be satisfied in cooperation. And I believe that we have recommended useful initiatives for the Department of Energy to consider as it pursues the topic.

John F. Clarke and Michael Roberts, of the Office of Fusion Energy, have lent their encouragement and substantive support throughout our study. The many individuals listed in the Appendixes, who participated in our domestic workshops and in our meetings abroad, thoughtfully and graciously supplied the substance of our work. My fellow members of the committee gave of their enthusiasm, their time, and their insights. Finally, we were ably supported by the staff of the Energy Engineering Board, led by Dennis F. Miller, its Executive Director, who was largely responsible for initiating the study. John M. Richardson, Study Director, provided day-to-day guidance and support. The cheerful and ready efforts of Cheryl A. Woodward in the full range of administrative matters was valued by all who worked with her. All these contributions I acknowledge with sincere thanks.

Joseph G. Gavin, Jr., Chairman
Committee on International Cooperation
in Magnetic Fusion

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SUMMARY

The United States, the European Community, and Japan are actively considering whether worthwhile advantages lie in increased cooperation among their respective programs of research and development in magnetically confined fusion. To help answer that question for the United States, this report examines why cooperation is a policy option, what might be done, and how.

LIST OF CONCLUSIONS AND RECOMMENDATIONS

For convenient reference the conclusions and recommendations of the study are collected together in this section apart from the arguments that lead up to them. The various supporting arguments are briefly developed at later points in the Summary, whereupon the conclusion or recommendation is stated anew.

The most important inferences from the many facts and viewpoints examined by the committee may be expressed in six specific conclusions:

- o On balance, there are substantial potential benefits of large-scale international collaboration in the development of fusion energy.
- o A window in time for large-scale international collaboration is now open.
- o Large-scale international collaboration can be achieved, but not quickly.
- o International collaboration will require stable international commitments.
- o There is a host of considerations that must be resolved in the implementation, but these appear workable.
- o Past cooperation provides a sound basis for future efforts.

Consideration of the above points in the broader context of the status and prospects for magnetic fusion development led the committee to an overall conclusion:

- o For the United States in the years ahead, a program including increased international collaboration is preferable to a predominantly domestic program, which would have to command substantial additional resources for the competitive pursuit of fusion energy development or run the risk of forfeiture of equality with other world programs.

Having concluded that large-scale international collaboration is the preferable course, the committee makes two recommendations for getting started:

- o The first priority should be the establishment of a clear set of policies and objectives and a considered program plan for future U.S. fusion activities.
- o Having carried out the preceding recommendation, the United States should take the lead in consulting with prospective partners to initiate a joint planning effort aimed at large-scale collaboration.

THE WORLD'S MAJOR MAGNETIC FUSION PROGRAMS

Major magnetic fusion programs are conducted in four areas of the world--the United States, the European Community (EC), Japan, and the Soviet Union. The four magnetic fusion programs are of comparable magnitude and are at a comparable stage of development. In each of these programs a "scientific feasibility" experiment based on the most advanced magnetic confinement concept--the tokamak--either has recently started operation (in the United States and the EC) or will start operation within the next one or two years (in Japan and the USSR, respectively). Smaller fusion programs are carried out in several other countries.

Broadly speaking, the near-term technical objectives of program planners in the four programs are similar: (1) to maintain a vigorous scientific base program, (2) to initiate a major next-step tokamak experiment, (3) to continue to develop the less mature alternative magnetic confinement concepts, and (4) to expand the fusion technology development program. Pursuit of these objectives is financially constrained, to varying degrees, in each of the four programs.

The physics of laboratory plasmas near fusion conditions is primarily an experimental science today. World leadership in fusion generally resides in that country possessing the experimental facilities with the greatest capability to explore the frontiers of plasma physics.

The United States

The United States has a strong experimental tokamak program that has established many of the world record plasma physics parameters. Two of these experiments, Tokamak Fusion Test Reactor (TFTR) and Doublet III D, should continue to extend the knowledge of plasma physics for the next five years or so. The United States also has the leading experimental program in the tandem mirror confinement concept, which is the most advanced alternative concept. Smaller programs are going forward in other, less advanced alternative confinement concepts, for example, stellarator, reversed-field pinch, and compact toroid. The United States has a strong program in basic fusion science and has the broadest and longest-established fusion technology program. For the past decade the United States has been the overall world leader in magnetic fusion, although upon occasion other programs have led in particular areas.

The European Community

The EC program is perceived by its participants to be on the threshold of assuming world leadership in fusion on the basis of a new generation of tokamak experiments, (commonly known by their acronyms as JET, TORE SUPRA, ASDEX-U, and FTU), that will be operating over the next decade. This view is shared by many in the United States. The EC program managers believe that they should maintain their progress toward leadership by constructing a major new tokamak experiment, Next European Torus (NET), to operate in the mid to late 1990s. NET has physics objectives of achieving an ignited plasma and a long-burn pulse and, in addition, ambitious technological objectives. Planning and preconceptual design work for NET has been authorized by the Council of Ministers of the European Community and initiated at the technical level; decisions as to whether to proceed to engineering design and to construction are scheduled for 1988 and 1992, respectively. The EC has programs in the less advanced stellarator and reversed-field pinch alternative concepts. Fusion technology programs are expanding in support of the NET activity. The EC fusion program is carried out in the various national fusion laboratories of its member countries and is partly funded directly by each nation and partly funded by the EC, with only minor participation by European universities.

Japan

The Japanese fusion program is relatively newer than the other three major programs, but it is moving rapidly toward full parity. The program of the Japanese Atomic Energy Research Institute (JAERI),

under the Science and Technology Agency, concentrates on the tokamak and on fusion technology. The JT-60 tokamak, which will begin operation within one year, will have confinement capabilities comparable to those of TFTR, although JT-60 is not designed for deuterium-tritium operation. Conceptual design studies are in progress for a new major tokamak experiment, Fusion Experimental Reactor (FER), to operate in the mid to late 1990s. FER would have objectives similar to those of NET. The fusion technology program is comparable in strength to the U.S. program, although not so broad. The university fusion program, under the Ministry of Education, Science and Culture, has funding comparable to the JAERI base program and conducts basic scientific and technological research that appears even broader than either the EC or U.S. programs. This program investigates several confinement concepts, including tokamak, tandem mirror, stellarator, reversed-field pinch, compact toroid, and bumpy torus. The reversed-field pinch is also being developed under a small program of the Ministry of International Trade and Industry. Of special note is the role of Japanese industry in designing and supplying complete systems to the fusion program; in this respect industrial involvement in Japan is greater than it is in the EC and U.S. programs.

The Soviet Union

The committee did not look into the fusion program of the Soviet Union. However, it is known that the USSR program is advanced to a level comparable with that of the other three major programs. The USSR program has historically been characterized by strong scientific insight. Past cooperation with the USSR has been technically fruitful and could beneficially be expanded from the rather modest current levels if U.S. policy constraints change. Circumstances may change sufficiently in the future to make renewed scientific cooperation with the USSR desirable from the policy viewpoint of each country, in which case fusion would be a suitable vehicle.

Implications for Cooperation

Three points made in the foregoing discussion have important implications for increased world cooperation: (1) the programs are at a comparable stage of development, (2) their near- to intermediate-term objectives are similar enough to provide a technical basis for a major expansion of cooperation in the future, and (3) maintaining enough strength to meet national needs will surely be a concern of each program.

PRIOR AND CURRENT COOPERATION

An open and informal exchange of scientific information through publications, meetings, and laboratory visits has existed among the United States, Western Europe, Japan, and the USSR since 1958, when the subject of magnetic fusion was declassified. The U.S. exchange with Western Europe has been the most extensive, probably because of cultural and political similarities.

A formal bilateral agreement with Japan has covered many cooperative activities over the past few years. For example, Japan is contributing approximately \$70 million over a five-year period to upgrade the Doublet III tokamak experiment and about \$2 million per year to the operation of the Rotating Target Neutron Source II in the United States, as well as sending experimental teams to work on those facilities. In addition, there has been extensive exchange of personnel on other projects and on joint planning activities.

There exist formal multilateral agreements among the United States, Japan, and the EC for several cooperative activities under the aegis of the International Energy Agency (IEA).

The United States, Japan, the EC, and USSR, under the International Atomic Energy Agency (IAEA), are cooperating in the International Tokamak Reactor (commonly known by its acronym INTOR) Workshop on conceptual design of a possible next-step tokamak experiment.

The United States and USSR have exchanged personnel and visiting delegations of scientists under formal agreements dating from the 1973 Nixon-Brezhnev accord.

Previous cooperative undertakings in fusion have been substantial and generally successful. The participants generally believe that they benefited from the cooperation. The technical and program leaders in the U.S., EC, Japanese, and USSR fusion programs have come to know and respect each other through many years of open professional and social contact. This rapport provides an unusual and unique basis to build upon in negotiating and carrying out cooperative activities.

This background is important enough to the issue that it should be expressed as a conclusion:

- o Past cooperation provides a sound basis for future efforts.

TECHNICAL OPPORTUNITIES FOR INCREASED COOPERATION

As the major fusion programs progress toward larger experiments and expanded technology development, there will be opportunities for increased benefit through enhanced international cooperation. In the following discussion, the term "cooperation" is used as a general one, in the sense of acting with others for mutual benefit on either a small or a large scale. The term "collaboration" is used more

specifically to imply working actively together as approximately equal partners in sizeable enterprises.

Major Next-Step Tokamak Experiments

The EC and Japan are planning experiments (NET and FER) with ambitious physics and technology objectives. These experiments are intended to be initiated at the end of the 1980s, after the essential results from TFTR, JET, and JT-60 are available, and to be operational at the end of the 1990s.

If the United States initiates a next-step tokamak project within the next several years, then the Japanese and Europeans could be invited to participate in a U.S. project. The Japanese and Europeans might be interested in providing components for the project if those components incorporated technologies that were relevant to their subsequent FER and NET experiments.

On the other hand, if a next-step tokamak project is to be delayed beyond the next several years, the United States should explore the possibility of joining with Japan and the EC, on a roughly equal basis, in an international project to plan, design, construct, and operate an experiment with objectives similar to those of FER and NET. The participation could be staged, with decisions on continuation made at the end of each stage.

The physics of tokamaks can be also advanced by experiments on intermediate-level devices with special characteristics, such as TEXTOR, ASDEX-U, and TORE SUPRA. Experiments like these offer technical opportunities for useful international cooperation, in preparation for collaboration on the larger devices.

Fusion Technology

The United States should explore the possibility of joining with Japan and the EC in a three-way effort to identify what information and what new fusion technology facilities will be needed and when, specify the design requirements and experimental programs for such facilities, and identify how the cost and responsibility for constructing and operating these facilities might be distributed equitably among the parties. Agreements among the three parties to participate in a national test facility project of one of them could then be worked out on a case-by-case basis.

Alternative Confinement Concepts

The United States is developing the tandem mirror, stellarator, reversed-field pinch, and compact toroid concepts and is investigating

other possibilities at a lower level of effort. Japan is developing the same four concepts, and Europe is developing the stellarator and reversed-field pinch. The development of each concept proceeds through a sequence of steps from small "exploratory" experiments through "intermediate" experiments to larger "scientific feasibility" experiments. In recent years the United States has retreated somewhat from this procedure, making it more difficult for a concept to advance to the next step or even to continue.

The United States should consult with Japan and the EC on cooperation in the development of alternative concepts. This cooperation could take two forms: (1) coordination in specifying the design parameters and experimental programs for intermediate experiments in each country so as to enhance their complementarity and (2) distribution of the responsibility among the three parties for constructing and operating scientific feasibility experiments as national projects in which the other party or parties would participate as junior partner(s).

INCENTIVES FOR AN INCREASED LEVEL OF INTERNATIONAL COOPERATION

The U.S. program has benefited from the the prior international cooperation described above in two quite different ways: resources were available to support effort beyond what could be supported in the United States alone, and novel and unique foreign contributions have influenced the U.S. program technically. One example of financial benefit is the Japanese contribution to the U.S. Doublet III tokamak, which allowed the additional heating equipment to be installed that led to the achievement of record plasma parameters. A prime example of technical benefit is found in the invention of the tokamak confinement concept in the USSR. As a consequence, all four major programs have advanced more rapidly and with better direction than would have been the case without cooperation. Similar benefits may reasonably be expected from future cooperation.

Greatly increased resources are required to maintain the breadth and depth of the national fusion programs while moving forward to explore a burning plasma in a major next-step experiment and to develop fusion technology. There seems to be an increasing body of opinion among responsible leaders in government and in the fusion programs in the United States, the EC, Japan, and the USSR that a cooperative international pooling of national resources may be required in the present economic environment. Such pooling would allow sharing of the increase in costs otherwise required of each separate program. The JET project is a good example of how national programs can be maintained at the same time that national resources are pooled for an international project.

Controlled fusion is the subject of one of the working groups established in 1982 by decision of the Heads of State and Government at the Versailles meeting of the Summit of Industrialized Nations. The Heads of State have subsequently endorsed the activities of the working groups. The fusion working group has identified the importance and magnitude of the effort of developing fusion and has concluded that a substantial increase in international cooperation is justified.

The extent to which any national or multinational fusion program will be willing to rely on international cooperation rather than its own strength and direction is a policy issue, the resolution of which may place constraints upon such cooperation.

Thus the main incentives for increased international cooperation are the expectation of enhanced technical results, probable cumulative savings--through sharing of costs and risks--in human and financial resources compared to those required by a separate program, and long-run merit as seen at the heads-of-state level. The main hesitancy will center on the possibility of weakening the individual programs, but conditions can be set to maintain the desired vigor. For these reasons, we come to the following conclusion:

- o On balance, there are substantial potential benefits of large-scale international collaboration in the development of fusion energy.

FACTORS AFFECTING THE IMPLEMENTATION OF INTERNATIONAL COOPERATION

There are many technical, political, institutional, and other factors that define the context within which the possibilities for increased levels of international cooperation in fusion must be explored. Some of these factors are favorable and some tend to be constraining.

Fusion power plants are at least a few decades from commercialization. This time horizon provides a unique opportunity for cooperation over the next decade or two with little compromise of the competitive position that national industries might seek to create in a commercial fusion market of the future. As that time approaches, it should be possible to accommodate proprietary objectives by an orderly disengagement or by other measures commonly employed in today's technological industries.

The points made previously concerning the approximate parity in the status of the world programs, their similarity in objectives, the gathering momentum of the EC and Japanese programs, the existence of technical needs and opportunities, political and administrative receptivity, and the absence of near-term competition in the commercialization of fusion support the following conclusion:

- o A window in time for large-scale collaboration is now open.

The EC and Japanese fusion program plans have been developed in detail for the next few years and resource commitments have been made accordingly. Furthermore, any major collaboration must meet the requirements of the separate national programs and therefore must be preceded by substantial joint planning. Thus, international collaboration cannot be expected to produce any substantial annual cost savings from current levels over the next few years, although cumulative savings over the long run, in the sense described above, may be expected.

Broader U.S. policy considerations may be at odds with technical opportunities for cooperation. The USSR has proposed joint international construction of the next-step tokamak experiment, yet it is unlikely that U.S.-USSR collaboration is possible in the current circumstances. Japan is willing to discuss further major collaboration, but in the United States there exists a political sensitivity to Japan on economic grounds. On the other hand, the Europeans, with whom collaboration would be the least controversial, show little interest.

These points are related to the following conclusion:

- o Large-scale international collaboration can be achieved, but not quickly.

Despite the Magnetic Fusion Energy Engineering Act of 1980, the U.S. government is perceived in some quarters as lacking a firm commitment and a realistic plan to develop fusion. A clear policy statement on the goals of the U.S. fusion program and a corresponding plan to meet those goals not only would be helpful for evaluating proposed major international cooperative projects but also would improve perceptions of the U.S. commitment. By contrast, it would be a mistake simply to increase emphasis on international cooperation to compensate for less than a full commitment.

The programmatic and technical decision-making process is quite different in the United States, the EC, and Japan. In the United States, major programmatic and technical decisions can be taken by highly placed individuals or small groups, whereas in Japan such decisions are taken only after lengthy review and discussion at lower echelons lead to a consensus. In Europe such decisions are taken only after numerous committee reviews. These styles lead to flexible, and occasionally even erratic, evolution in U.S. policies and programs and to deliberate, and occasionally even cumbersome, evolution in EC and Japanese policies and programs. Accommodation of these different styles of decision making is necessary for large-scale cooperation.

The United States is also perceived in some quarters as an "unreliable partner" based on previous experiences in space science, synthetic fuels, and fusion itself. The annual funding appropriation process makes it difficult for the United States to commit to multiyear projects without the possibility of facing a choice later of either going back on the commitment or sacrificing other elements of

the fusion program. Requesting explicit budget items for international projects, after clear identification of the obligations implied for subsequent years, may ease the problem. Nevertheless the process makes an investment in a multiyear project appear as a high-risk venture to potential foreign collaborators, as well as to leaders of the U.S. fusion program. As a result, a formal and binding instrument might be necessary to assure potential collaborators on a major project that the United States would fulfill its part of the agreement.

All the above factors are embodied in the following conclusion:

- o International collaboration will require stable international commitments.

Technology transfer arises as an issue and a possible constraint in three areas: national security, protection of U.S. industry, and loss of advantage to foreign participants from technology developed by them because of provisions of the U.S. Freedom of Information Act mandating wide access to information held by U.S. government agencies. However, technology transfer does not seem to be a major concern at this time because of the remoteness of significant military or commercial applications of magnetic fusion.

There are numerous institutional choices for implementation of international cooperative arrangements. Treaties constitute the most binding commitments of the U.S. government but are the most difficult agreements to conclude. Intergovernmental agreements are much easier to put into place because they can be negotiated at lower governmental levels.

Existing international organizations, such as IAEA and IEA, offer auspices under which more extensive international cooperation could be carried out without the necessity of new implementing agreements. An expansion of cooperative activities under these agencies is reasonable. Neither of these agencies or other existing international organizations would be suitable as sponsors for a major international project because they function primarily as coordinators and administrators, not as managers, and because they have their own priorities. However, an existing international organization may provide a framework for initiating a project, as was the case with the European Organization for Nuclear Research (commonly known by its original French acronym CERN).

For fusion the most relevant example of a major international project is JET. The project was set up as a Joint Undertaking by the Member States of the European Community in 1978 under provisions of the 1957 Treaty of Rome, which established the European Community.

More generally, a joint international project is complicated, but it can work if it is carefully planned and skillfully executed. Organizations must be created to deal successfully with technical direction, administration, liability, and relationships with local and

national host governments. Mechanisms must be adopted for site selection, the capture of perceived commercial value, the ownership and sharing of intellectual property, and policy with respect to licensing technology to nonparticipants. The equitable participation of national industry must be accommodated, and technology transfer will have to be suitably controlled in instances that affect national security. Standards for safety and radiation will have to be harmonized, and subtle changes in the roles and missions of established domestic institutions will have to be faced.

The foregoing points all support the following conclusion:

- o There is a host of considerations that must be resolved in implementation, but these appear workable.

OVERALL CONCLUSION AND RECOMMENDATIONS

Three widely separated courses seem to be open to the United States on the path to fusion energy: (1) to make the commitment to become the all-out competitive leader in all its aspects, (2) to engage in large-scale international collaboration, or (3) to withdraw with the intent of purchasing the developed technology from others in the future. In actuality, the extreme first and third courses would not likely be so sharply drawn. Degrees of competitiveness, ranging from preeminence down to simple parity with others could be defined. Degrees of withdrawal, from slight to serious forfeiture of equality could be contemplated. Although the committee did not formally analyze the situation in this context, it still forms a useful setting for an overall conclusion, derivable from some of the individual ones stated earlier:

- o For the United States at this time, large-scale international collaboration is preferable to a mainly domestic program, which would have to command substantial additional resources for the competitive pursuit of fusion energy development or run the risk of forfeiture of equality with other world programs.

Given this overall conclusion, two major recommendations follow:

- o The first priority should be the establishment of a clear set of policies and objectives and a considered program plan for future U.S. fusion activities.

Such a position is necessary as the basis for discussions with potential partners and for any long-range commitments that ensue. Concrete near-term and intermediate objectives and a schedule for their attainment would be appropriate elements of the program plan.

The Department of Energy should formulate the position for the review and approval of the Administration and the Congress.

- o Having carried out the preceeding recommendation, the United States should take the lead in consulting with prospective partners to initiate a joint planning effort aimed at large-scale collaboration.

This joint planning activity would have to involve groups at the program leadership level and at the technical leadership level, in appropriate roles, and would have to be a continuing activity over many years. Quite plainly, an opportunity is open for leadership of a cooperative approach to a new technology of global significance.

INTRODUCTION

The United States, the European Community (EC), Japan, and the Soviet Union are all vigorously pursuing magnetic fusion as a preeminent scientific challenge and an energy source of tremendous potential benefit. The U.S., EC, and Japanese programs are each being conducted at the level of several hundreds of millions of dollars per year. The next stage of development will require sharply increased effort, and power-producing test or demonstration reactors after that will call for investments of billions of dollars. These demands, if placed on each program, will strain the available human and material resources, with the possible consequences of delayed results, limited scope, and greater risk. Given these prospects, in combination with the history of prior successful international cooperation on a more modest scale, might a significantly greater level of cooperation bring a number of worthwhile returns?

FUSION ENERGY AND THE QUESTION OF GREATER COOPERATION

Magnetic fusion refers to the large-scale production of nuclear reactions involving the lighter elements, using magnetic fields to attain the necessary density and duration of confinement of the reacting nuclei as components of a fully ionized gas, called a plasma. Magnetic fusion research began some 30 years ago with independent classified programs in the United States, the USSR, and the United Kingdom. In 1958 these programs were declassified and an era of information and personnel exchange began. In the intervening years separate programs in the United States, the EC, Japan, and the USSR have grown to their current substantial status.

The Path to Fusion Energy

The United States, the EC, Japan, and the USSR are each committed to pursue fusion as a potential element in their energy futures, although

the degree of the commitment differs. It is not possible, however, to proceed forthwith toward the objective of widespread availability of fusion energy in the same way one might proceed directly toward the design, construction, and deployment of a new aircraft. The reason is that much of the necessary science and technology has yet to be developed. (See Conn, 1983.)

The technical path to fusion requires showing its scientific feasibility through convincing theory and substantiating experiments that the laws of nature will allow more energy to be produced from the plasma than is necessary to supply to it to induce the fusion reactions. Next, engineering feasibility must be established through the choice of a suitable design concept for a reactor and the development of advanced technologies necessary for the production and extraction of useful amounts of power. In actuality, significant overlap exists between the two feasibility conditions, so that the terms are really more useful as simplifying concepts than as distinct developmental stages. A demonstration of power production on a commercial scale will probably be considered necessary to convince users that some form of commercialization is possible. Finally, attainment of economic viability in comparison with alternate technologies for generation of power will be required. Currently, investigations are at the stage where scientific feasibility is expected to be shown within a few years.

The strength of the commitment to fusion energy in the several world programs varies because of varied national circumstances. Japan, for example, has few indigenous energy sources and has decided to explore both fusion energy and fission breeder reactors to meet its foreseeable needs. The EC must similarly explore alternative technologies, although its energy needs are neither so immediate nor so acute as those of Japan. The United States, currently enjoying greater reserves of coal and uranium, probably feels the least urgency about fusion. The USSR has its own objectives for a substantial program in magnetic fusion energy. This report is concerned with the programs of the EC and Japan as the most likely candidates for cooperation, and it has comparatively little to say about the USSR program.

The four world programs are certainly competitive in the technical sense with both implicit and explicit rivalry for technical accomplishment. The current stakes are the natural ones of professional recognition and national accomplishment. There seem to be no prominent overtones of any national race to arrive first at some sharply defined fusion goal, such as there was with respect to a moon landing or such as there is with respect to the development of a supercomputer of a specified speed.

Structure of the Question

In principle it would be logical first to examine the technical program substance for cooperative opportunities, then to examine the

advantages and disadvantages of particular candidate projects, and lastly to examine various kinds of agreements capable of reaching the desired ends. In practice, however, both the incentives for cooperating and the constraints thereon will feed into the policies governing cooperation. Accordingly, the nature of these incentives and constraints, as they appear to all of the cooperating parties, is of first concern, assuming for the moment that there are ample technical opportunities for cooperation and that there are also ample ways to agree how to carry it out.

One important incentive is achieving needed program results sooner or more completely through joint efforts than is possible by any single partner without cooperation. Another incentive is expanding, and capturing, long-term economic benefits from eventual commercial application of fusion to a greater extent than might be realized from a separate program. Saving research and development costs is often mentioned as an incentive, a feature of particular interest to finance ministries and to officials who must allocate resources over the whole range of competing national needs. Similarly, diversity of technical approach can spread the risks, with possible avoidance of costs. Political objectives, such as the strengthening of economic alliances, have been served in the past by cooperation in fusion and may provide future incentives. Another incentive to cooperation is to broaden the base of interest in fusion. A broader base of interest may help electric utilities, as potential users, to arrive at decisions regarding their own role and may, in addition, involve more manufacturers as suppliers of both experimental and commercial equipment. Public awareness of the technology may also be enhanced, a necessary condition, at least, for eventual public acceptance.

The foregoing incentives for cooperation are overlaid with constraining policy objectives. Each country will have some preconceptions as to the proper degree of its national program strength and independence. Other policy objectives will be to attain national prestige through technical leadership and to avoid the impairment of national security through, say, undesirable technology transfer.

The technical needs and opportunities for cooperation fall into three categories: basic information in plasma science; fusion technology, including engineering component development; and construction and operation of major experimental facilities. The modes of technical cooperation may be conveniently divided into five categories: exchanges of information at meetings and workshops, exchanges of personnel at research facilities, joint planning for effective collaboration on and increasing the complementarity of new facilities, joint programs on unique national facilities, and the joint undertaking of all aspects of major facilities.*

*In this report the term "cooperation" is used in the general sense of acting with others on either a small or a large scale. Where the more specific sense of working actively together as approximately equal partners in sizeable enterprises is intended, the term "collaboration" is used.

Agreements for implementation of cooperative projects must deal satisfactorily with a number of factors that bear on policy objectives, mutuality of purpose, and conditions for working together. The principal factors are timing, compatibility of goals, stability in the partnership, technology transfer, flow of funds among partners, equitable distribution of the benefits of cooperation, suitability of institutional framework, and workability of the arrangements for project management.

It is in these terms that the report discusses whether greater cooperation is desirable and, if so, what might be undertaken and how.

THE WORK OF THE COMMITTEE

The main task set for the committee was to recommend, for the consideration of the U.S. Department of Energy (DOE), courses of action for international cooperation, analyzed with regard to technical need, relevant national policies, workability, long-term implications, and other criteria of suitability. (See Appendix A for a fuller description of the Scope of Work.) It was expected that the committee would not advise on the content of particular technical projects and programs but would merely identify topics as candidates for cooperative program definition. However, as the committee approached its task, it soon perceived a lack of complete world readiness for large-scale cooperation. Hence the problem of the committee was more one of finding ways to move toward that readiness than of straightforwardly analyzing technical proposals in terms of well established criteria.

Committee Inquiries

The first step of the committee was to explore in some depth viewpoints within the United States in order to fill out the structure of the problem described in the preceding section. Thus, two workshops were conducted to gather domestic views. It was thought impossible to separate cleanly the technical, policy, and organizational aspects of the question so that these might be dealt with in different workshops. Consequently, all three aspects were treated together. Two workshops, covering the same ground but with different participants, were conducted in order to reap a diversity of viewpoints and to ascertain those viewpoints that both groups agreed on. These workshops solicited prepared inputs over a wide range of experience. We heard from management levels of the fusion program of DOE and from the various parts of the technical fusion community itself. We heard from other parts of U.S. government--in particular, from the Department of Defense, the Department of State, and from Congressional staff. We heard individuals who had lived through prior

examples of international cooperation in fusion as well as other technologies quite unrelated to fusion. Individuals with experience in the later stages of commercial development of technologies, such as jet engines, computers, and semiconductors, gave us the benefit of their experience. We also obtained the viewpoints of individuals from electric utilities as ultimate users of fusion technology and from the financial community as a source of investment in commercial fusion. Finally, we sought the ideas of those experienced in diplomacy and international law, such as negotiators of the Treaty of the Peaceful Uses of Outer Space and the Law of the Sea.

Of course, it was essential to make first hand contact with scientists and policy level officials in Japan and in countries of the EC. Accordingly, committee members traveled to Japan and to Western Europe to address many of the subjects covered in the domestic workshops, although necessarily in less depth. The travelers attempted to discover compatibility of the various national goals, or the lack thereof. Foreign officials were asked about the intended development of the role of their domestic industry; and their attitudes were sought on cooperation with the United States, which in the last analysis, may determine the response to any U.S. initiatives.

These meetings also inquired into the technical needs and opportunities for cooperation at several levels of effort: modest scientific exchange, organized cooperative planning and study, plasma physics experimentation, large technology test facilities, and major experimental fusion facilities.

The discussions also covered the types of agreements, organizations, and management arrangements that might be adapted to implement cooperative efforts. On the trips, the group examined the characteristics of successful efforts at cooperation, such as the Doublet III experiment, jointly funded by Japan and the United States; the Rotating Target Neutron Source II experiment, similarly conducted; the studies on the German TEXTOR tokamak of impurity control and physics of the plasma edge, under the auspices of the International Energy Agency; and the Joint European Torus, an example of successful resolution of divergent national and cultural interests. The group heard also about other projects such as the Large Coil Test Facility, which has been troubled by scheduling delays, and the Fusion Materials Irradiation Test Facility, for which the United States has not yet been able to conclude an agreement on joint participation.

Organization of the Report

In the remainder of the report, Chapter 2 deals with the incentives and constraints that constitute the policies governing international cooperation and from which will flow the criteria for judging international cooperative initiatives. Chapter 3 discusses the technical needs and opportunities from which the substance of

cooperation may be drawn. Chapter 4 examines factors affecting agreement on and implementation of cooperation. Finally, Chapter 5 contains our conclusions and our recommendations for the near future together with the rationale supporting them. Several appendixes, providing more detail on topics discussed in the main body of the report, are included.

INCENTIVES AND CONSTRAINTS

International cooperation is an amiably received proposition throughout the fusion community, being widely perceived as a way to broaden the bases and relieve financial strains of national fusion programs. Yet to arrive at sound recommendations about whether to extend international cooperation, one must examine the incentives and constraints, especially those that arise from broader policies. One must also examine the perception of these factors by the various groups concerned with cooperation. Finally, one must weigh the expected consequences, even though these cannot be known with certainty.

INCENTIVES AND CONSTRAINTS AT THE POLICY LEVEL

Incentives

There are a number of incentives, consistent with broad policy goals, that the conventional wisdom widely accepts in a general sense (Rycroft, 1983). Nevertheless, when one goes from the general incentives to specific programs and project details, some reluctance toward international cooperation seems to appear.

Achieving Program Results

International cooperation makes possible a much broader and more diverse program in pursuit of its fusion goals than could be supported by any single nation within presently anticipated budget limits. The information flow available to a national program is thereby increased and broadened; there are more people working in more areas and generating more new ideas and ways of attacking problems; and the chances of generating step advances in the science and technology of

fusion--the breakthroughs or lucky accidents that both enliven and accelerate progress in research areas--are usefully increased.

The sharing of scientific and technical information through international cooperation reduces national program risks and improves program opportunities. All research and development efforts have elements of risk through the pursuit of scientific or technological directions that subsequently prove unfruitful. Access to the broadest possible information base improves the chances of avoiding unfruitful ventures and of recognizing opportunities for progress.

Moreover, through the sharing of test facilities and projects for materials and technology development, needed technological results may well be acquired sooner and in greater depth than otherwise.

There is also the point noted by Rose (1982) that in the past capable people have come into the fusion field who might very well not have done so had the activity not offered the opportunity for international contacts. Inasmuch as fusion research and development efforts are likely to have to continue for a good number of years into the future and that the long-term vigor and viability of such programs will depend substantially on the scientific and managerial abilities of the program leaders, the broader, more diverse, and more comprehensive programs made possible by international cooperation should be an important element in attracting the most capable people to the field. The point is a far from trivial one in planning for the very long-term kind of effort that fusion power will surely require.

Expanding Economic Benefits

Rose (1982) also observes that international cooperation in fusion has been a very positive-sum game to date. Programs of all the participants have advanced more rapidly and with better direction than would have been the case without the cooperation (U.S. General Accounting Office, 1984). It is reasonable to expect that this quality, of yielding substantially more program benefits than the funds and effort invested, should be a feature of international cooperation for some years to come. Because everyone gains from the collaboration and the whole amounts to more than the sum of the contributed parts, it should be less important that supplies and equipment contracts in a collaborative effort be distributed with great precision according to the contributions of the collaborators.

The long-term economic benefits that will flow from the full commercialization of fusion through any particular national program are expected to be great, although their exact nature and magnitude cannot be foreseen with certainty. Cooperative programs, through their greater technological diversification, may be able to expand both the scope and the scale of the benefits ultimately available to each participant. The equitable capture of these benefits, of course,

will have to be possible under whatever cooperative arrangements are undertaken.

Saving Costs of National Programs

As fusion research and development moves towards large machines and supporting facilities, it becomes highly expensive and difficult for any single nation to support a comprehensive program. International cooperation and the sharing of some costs, including the joint construction and use of expensive installations for which only a single facility of a given type is considered necessary and sufficient, offer relief from national budgetary limitations.

Unnecessary duplication of effort is avoided by the distribution among the members of an international cooperative effort of those tasks that can be shared. Some duplication of effort is inevitable to satisfy the interests of national partners in acquiring "hands-on" experience, but international cooperation can substantially reduce the overall level of duplication and thereby improve the efficiency of use of everyone's limited funds.

Serving Political Objectives

There is a more recent incentive that has considerable meaning for government program managers and staffs. Controlled nuclear fusion is the subject of one of the working groups set up, in the summer of 1982 by decision of the Heads of State and Government at the Versailles meeting of the Summit of Industrialized Nations, to serve the larger political objective of technological cooperation among certain industrialized countries (Science, 1983). In June 1984, the leaders of Canada, Italy, France, the United Kingdom, Japan, West Germany, the United States, and the European Community (EC) endorsed the activities of the working groups in exploring plans for closer collaboration in science and technology in the industrial nations (Science, 1984). The working group considering fusion, in which the United States participates, noted the long-range importance of the technology and the magnitude of human and financial efforts needed and concluded that a substantial increase in the level of international collaboration is justified. Endorsement at the head-of-state level for international cooperation in fusion, even couched in the most general terms, is a powerful influence in determining the attitudes with which government staff and negotiators approach the subject.

From time to time technological topics have been selected to serve, in whole or in part, broader political objectives, such as strengthening alliances, creating good will, or augmenting a particular negotiation. Examples are the United States-Japan space launch agreement, the proposal for an international telecommunications satellite consortium, and the provision of desalinization technology to Middle East countries. Indeed, the EC points with pride to its

magnetic fusion program as a successful example of its political goals for European cooperation in large-scale research and development. Other political objectives may arise that can be served by international cooperation in magnetic fusion and will thus provide incentives.

Broadening Constituencies

International cooperation can improve public, political, and electric utility confidence in and acceptance of fusion as an eventual power source. Stability of the fusion programs of the participants is another benefit. Indeed, cooperation will demonstrate a wide agreement among different peoples and different points of national view that practical fusion power sources can be developed and that--on cost, resource, and environmental grounds--fusion power may be at least as acceptable as other alternatives if not superior. Cooperation will also create a sense that not to go forward with fusion is to be left at a disadvantage in the future.

The Member States of the EC, together with three other nations, namely, Sweden, Switzerland, and Spain, have long since recognized the weight of the incentives over the constraints for international cooperation in fusion. These nations have formed a comprehensive and sound research and development program that has produced the leading tokamak, Joint European Torus (JET), as well as early planning efforts for a subsequent large machine. Further levels of international cooperation, between the United States, the EC, and Japan can and may respond to the same incentives, although with different arrangements to deal with the differing constraints and limitations.

Constraints

Just as there are incentives that are widely accepted in the fusion community, so there are some constraints and disincentives under existing policies that are also recognized at a general level. Like the incentives, the general constraints tend to weaken in the face of detailed consideration and negotiation on specific cooperative enterprises. So, in the regime of details and specific projects, just as the incentives appear less clear and forceful, so the constraints become less important as particular ways of dealing with each one are sought and developed.

Maintaining National Program Strength

There is reluctance for national programs to give up any significant part, scientific or technological, of what is seen as the main line of advance toward an eventual fusion power plant. This reluctance is, in

part, national preparation to satisfy domestic energy needs and, in part, national protectiveness for domestic industries and for a competitive position as an eventual supplier of fusion plant equipment. This policy constraint gives rise to the question of technology transfer in the implementation of cooperative programs.

If it is true that national research and development budgets are tight and that international cooperation is seen as a way to share costs and maintain comprehensive programs, then it is also true that the funds available for international cooperation are not unlimited. And the funds that are contributed from national programs to international cooperation will be, at least in part, at the sacrifice of some elements of the national programs.

Preserving National Program Prestige

There is a similar reluctance to give up national prestige that comes from successful technical and professional competition. It is a natural instinct of project managers, laboratory directors, and government program officers to seek to maintain and extend world leadership. These instincts are reinforced by the prospect that national objectives may be in some sense endangered by giving up certain program management authority. However, there can be no international cooperation without some financial cost and some surrendering of national control to the joint enterprise.

Safeguarding National Security

A policy constraint that must be taken into account is to avoid impairment of national security through disclosure of militarily useful technology to potential adversaries. The degree of constraint will depend principally on the way that the question of technology transfer is perceived and handled in the implementation. The committee does not suggest that national security imposes serious limitations on international cooperation in fusion with the Western countries; rather, the topic is included here for completeness and is discussed more fully in the chapter on implementation.

PERCEPTIONS OF INCENTIVES AND CONSTRAINTS BY VARIOUS U.S. GROUPS

There are diverse perceptions of the incentives and constraints for international cooperation in fusion among the senior technical leaders in the U.S. program, government program administrators, high-ranking administration officials, Congressional oversight and appropriation committees, manufacturing industries as suppliers, and electric utilities as users. (See Appendix B.)

Technical Leaders

The technical community in the U.S. fusion area, at least as represented by the consensus of the Magnetic Fusion Advisory Committee (MFAC), strongly supports international cooperation on a general basis. MFAC made the following declaration:

The U.S. fusion program and the development of fusion on a worldwide basis have benefited significantly from the active exchange of information and ideas. International cooperation in fusion research should continue to receive strong emphasis in the U.S. program. The planning of national fusion facilities and programs has been guided to considerable extent by a policy of avoiding international duplication and instead addressing complementary technical issues. This policy is both cost-effective and conducive to rapid technical development. It encourages broader coverage of options in the area of alternate concepts and allows larger steps to be taken in the main-line approaches within existing budgetary constraints.

--Magnetic Fusion Advisory Committee, 1983

MFAC goes on to note that within each confinement approach, U.S. effort has been largely complementary to activities in other nations. For example, each of the four large tokamak projects that were undertaken in the mid 1970s--Tokamak Fusion Test Reactor (TFTR) in the United States, JET in Europe, JT-60 in Japan, and T-15 in the Soviet Union--has a distinct set of characteristics and objectives. The MFAC report continues:

While maximum effective use should be made of research facilities abroad, to supplement U.S. capabilities, the overall priorities of the U.S. program should continue to emphasize the most promising reactor approaches. The international fusion effort will benefit from increased consultation in program planning and from the initiation of coordinated--or even jointly supported--research projects.

The thrust of MFAC's recommended U.S. program and strategy for the coming years, however, has a central theme of "going it alone" with regard to major new steps. The MFAC recommendations have been for maintenance and continuation of the U.S. base program in magnetic fusion and for early initiation of a major new facility, the Tokamak Fusion Core Experiment (TFCK), with an increase in the U.S. fusion budget ramping up over several years to a new level 25 to 40 percent above the present one in constant dollars. Present international cooperative ventures would presumably be continued and opportunity sought for additional exchanges, at least on an information sharing basis; but there is no suggestion in the MFAC plan of more ambitious collaborative ventures.

One can sympathize with program technical leaders who would much prefer to be fully supported by the U.S. domestic budget in a comprehensive research and development program including major new machines at appropriate intervals. That prospect is certainly a more pleasant one than contemplating heavy cuts in the base program in order to provide funds for a major new machine within current budget limits, or surrendering substantial elements of technology and of management control in the next major machine to international partners in a joint venture, or, most likely, both. If the increased funding can be obtained, then the MFAC recommendations certainly lead to a very strong U.S. position in fusion and are probably the actions of choice. However, if U.S. fusion program budget levels are to remain at current levels, or to diminish slightly as suggested by recent Congressional actions on the FY 1985 budget, then the options appear to be to reduce the base program substantially to accommodate TFCX (or other major next-step tokamak), to maintain the base program and delay indefinitely TFCX, or to seek substantial international collaboration on the next major tokamak together with some base program cuts.

Program Administrators

The views of U.S. government program administrators on international cooperation in fusion are consolidated into the Comprehensive Program Management Plan (CPMP) for magnetic fusion, prepared by the U.S. Department of Energy (1983). The CPMP states current U.S. policy with respect to leadership in magnetic fusion in the following terms:

The Department's intent is to maintain a leadership role for the United States in the area of magnetic fusion energy research and development.

The term, "a leadership role," pointedly indicates that the United States is to be among the leaders and lead in some areas but not others, rather than to move aggressively into the world leadership position in magnetic fusion--a position it has had at times in the past. At least one implication of this policy for the prospects of increased international cooperation, particularly for cooperation in major next-generation machines, comes to mind: other nations may be less enthusiastic about entering arrangements with a program that is, at best, even with their own.

The current U.S. policy on international cooperation is stated in the following terms in the CPMP:

The Department intends to maintain this position [of leadership] in the two major confinement concepts and in the development of critical technologies. We recognize that progress can best be made through a carefully formulated and managed policy of close international cooperation to share specific tasks.

This statement suggests an affirmative policy toward international cooperation, but on a selective basis and with close controls on project scope and activities and on technology aspects to be shared. The phrase "to share specific tasks" was understood to mean that the United States would attempt to retain all essential technologies within the U.S. program. The implications for international cooperation are that hard bargaining as to technical and fiscal contributions and as to the sharing of results will be involved in arranging any joint projects.

The current goal of the U.S. program is stated as follows in the CPMP:

...to develop the scientific and technological information required to design and construct magnetic fusion power systems.

This overall objective of the program is more limited than the visions of some years ago and reflects current budget constraints. The CPMP does not contemplate a prototype power plant in the U.S. program and may leave a substantial gap between the government program and any serious attempt at commercial use of the technology. In particular, the CPMP leaves to potential commercial users the development of an industrial base for the fabrication and construction of fusion power plants. Since at least one and perhaps all of the major foreign magnetic fusion programs seem directed toward an eventual goal of controlling and marketing fusion plant technology, there may be significant problems of compatibility in basic goals in agreeing on international joint ventures.

The CPMP does call for a large machine, the Engineering Test Reactor (ETR), to be built in the late 1980s, but recent budgetary constraints caused planning at the technical level to be directed towards a less ambitious next step, TFCX. TFCX embodies the physics of ETR but little of the technological and engineering testing features. During the writing of this report this goal has been set aside, and a revised plan is not yet available. The Japanese, EC, and Soviet program plans in magnetic fusion continue to contemplate an engineering test reactors* of roughly similar objectives. Decisions would be taken in the late 1980s or early 1990s and, if favorable, the machines could be ready by the late 1990s. These machines in the foreign programs would then be followed by demonstration reactors.

U.S. government program administrators recognize the potential benefits of international cooperation on a wide scale and, faced with the realities of current budget levels, look to it as an essential part of a successful fusion program. Situated precariously between would-be budget cutters at some levels in the administration and in the Congress and would-be budget raisers in the technical community, the government program administrators' task is to develop a consensus on a reasonable program that balances the dual needs to maintain a strong base program and to move ahead with the next major machine, includes

*Designated as Fusion Engineering Reactor (FER) in Japan, Next European Torus (NET) in the EC, and OTR in the USSR.

substantial international cooperation, and operates at realistic budget levels--an admirable but difficult task.

Administration Officials

The fusion-related views of high-level U.S. administration officials seem concentrated on program cost matters. Budget officials are unenthusiastic about significant new commitments to large projects, or to increases in base programs either. The President's Science Advisor has talked of a "balanced fusion program," which is to advance with due deliberation, obtaining a maximum of information available from each step and taking full advantage of progress in other technical fields and in other countries. International cooperation would be judged in both quarters, one expects, on its promise to reduce overall U.S. fusion program costs or at least help to hold them level.

Congressional Committees

The Congressional authorization committees tend to be fusion program supporters and inclined toward a comprehensive U.S. program including new machines. The appropriation committees are mainly interested in accomplishments in relation to costs. Recent actions on the fusion budget for fiscal year 1985 were accompanied by questions on the readiness of the U.S. program to advance from a scientifically oriented program to an applications oriented program so soon. In particular, there was a concern that funding the planning for TFCX before full results were available from TFTR might be tantamount to a premature choice of a particular reactor concept. Thus, along with cutting the fusion budget, the appropriation committees admonished the Department of Energy not to damage the base program in favor of TFCX or other new machines.

In general, it may be expected that the Congressional committees will act positively and decisively only when there is consensus on goals, objectives, and program content and when the costs of these are commensurate with probable benefits.

Industry Executives

Apart from those of a few specific firms, executives of the manufacturing industries as suppliers and the electric utilities as users of eventual fusion power systems evince polite interest in the whole subject, including international cooperation, and not much more, principally because the commercial aspects of fusion are so far in the future. There is not much business to be done in fusion for the present; and what there is involves difficult technologies to which American manufacturers seem reluctant to accord matching priority, talent, and energy.

EUROPEAN AND JAPANESE PERCEPTIONS OF INCENTIVES AND CONSTRAINTS

These impressions are culled from the visits of the committee to Japan and the EC to talk to fusion program leaders there. Summaries of these trips appear as Appendixes C and D.

In general, the Europeans and the Japanese seem affected by the general incentives and constraints for international cooperation in much the same way that Americans are. There is some feeling that fusion research and development budgets are not unlimited and that international cooperation, as it has in the past, can be an aid to achieving program results. At the moment, the Europeans and the Japanese seem to feel this incentive less strongly than the Americans. Some other observations indicating European and Japanese perceptions of the incentives and constraints of international cooperation are noted below.

European Perceptions

For a number of Europeans, the perceived need for fusion was not especially strong in view of other energy sources and supplies. Fusion work was classed mainly as an "insurance policy." While the long-term economic benefits from fusion were thought by the Europeans to be great, those benefits cannot be estimated accurately at present. There is, therefore, in the European view, no quantitative justification for any particular program scope and pace. With any deployment far in the future, fusion development programs must be funded entirely by the public sector. The utilities in Europe wait and watch without investing in fusion.

At the political level in the EC, international collaboration on fusion research and development is considered desirable. Cooperation with both the United States and Japan has been endorsed. However, it was felt that the three world-class programs would have to be brought into better coordination in order to enjoy full cooperation on the next large step.

The fusion collaboration within the EC and the product of that collaboration, JET, is viewed with much pride. Indeed, there is some expectation by its participants that the EC tokamak may shortly achieve the leading technical position in the world. There is a desire on the part of some EC participants to maintain the self-sufficiency of the EC program and not to broaden the scale of cooperation to the extent that EC unity might be diminished (Commission of the European Communities, 1984a). Thus, preservation of the unity and coherence in the EC program may be an important constraint on any further cooperative planning and may even diminish interest in large-scale collaboration beyond the EC.

Japanese Perceptions

The Japanese appear to have a firmer and more consistent government energy policy than the United States, stemming from their lack of natural resources. They intend to be successful with fission breeder reactors and eventually with fusion. Compared with the United States and the EC, Japan seems to have more direct industrial participation in fusion programs. As for the Japanese utilities, they are more centralized, appear to be more financially sound than in the United States, and are somewhat more involved in the fusion program.

Japanese industry is actively involved as supplier of experimental equipment (Japan Atomic Industrial Forum, 1983). The industry has exhibited interest in acquiring and protecting fusion technology "know-how." Industry representatives of the Japan Atomic Industrial Forum expressed a generally negative attitude on international cooperation, which seemed to be motivated primarily by their desire to establish industrial leadership. They did not appear concerned that financial constraints might reduce the fusion program or stretch out the period over which it is carried out. They also indicated that Japan should not rely on any other country for the development for any technology that is critical. One form of cooperation proposed by the Japanese industrialists was to let Japanese vendors supply components to the U.S. fusion effort, provided that similar technology promised to be useful to the Japanese program as it progressed.

A generally positive attitude about international cooperation was expressed by government ministry officials, by fusion program leaders, and by influential advisors. The incentive seemed in all cases to be concern about current or future Japanese financial constraints. If fusion were near the application stage, there might not be any Japanese interest in international cooperation. However, with the commercial application of fusion decades away and total development costs running into tens of billions of dollars, it is difficult for anyone to be against international cooperation, especially since Japanese funding seems to have leveled off just as it has in the United States. Program administrators see international cooperation as a means of conserving scarce resources. Scientists see cooperation as a means of expanding or accelerating the fusion program. All groups except the industrial one endorsed international cooperation in principle as desirable or necessary for technical progress, risk sharing, and cost sharing.

It was a Japanese view that international cooperation must not impair national programs. Therefore, cooperative efforts will have to be supplementary to the main core of these programs or else, if more extensive, will have to fit well with the national program content. In the case of collaboration on a major project the parties should start with joint formulation of the objectives, schedules, design features, and so forth. This approach would apply when the collaborating partners had approximately equal shares in the venture.

The Japanese summarized a number of desirable principles for international collaboration. These included the following points: no erosion of the national programs, mutual benefit, participation on an equal footing, assurance of continuity in the collaboration, acceleration of the national program of the partners, overlap of program interest, achievement together of what is not achievable separately, full participation in planning from the beginning, and full access by all sectors to the technology developed.

QUESTIONS ABOUT INTERNATIONAL COOPERATION

There are a number of questions about international cooperation that may illuminate useful policy boundaries and criteria for cooperation. The answers to these questions by various groups within the U.S. and by the Europeans and Japanese may very well be somewhat different as suggested in the following discussion.

Will International Cooperation Accelerate Technical Progress and Return on the Technical Investment?

It almost certainly will in the long run. As noted in the discussion of incentives, there may be synergistic effects from international cooperation that multiply the return on investment in assorted ways. These effects are almost certain to work in the future with international cooperation as they have in the past and to be in addition to the more direct and obvious features of allowing a project to go forward in a cooperative effort where it would either not be possible or would be delayed in a single national program. There are matters of timing involved, however. Note, for instance, the concern voiced in both Japan and the EC that discussions about joint ventures in TFCX and in the next Japanese and EC machines, FER and NET, might delay those machines.

Will International Cooperation Allow Us to Cover Technical Ground That We Could Not Otherwise Cover?

Yes, it will, especially in large-scale collaborations, such as JET, by providing access to a technically broader program than we could maintain by ourselves at a constant budget level. The same is true, of course, for other partners in the collaboration.

Will International Cooperation Gain Us a Competitive Edge in Future World Markets?

If international cooperation is continued to the commercialization phase, it probably would not put us ahead of the other major partners

in the cooperation. Nor would it give any of the partners any particular edge over us. What international cooperation will do in that case is to keep us well informed in a technological sense and thus help us to maintain a competitive competence among equally competent potential suppliers of future markets.

If international cooperation is continued only through the phases of scientific inquiry and generic technology development, with disengagement of the partners or other common measures for protecting proprietary interests as commercialization approaches, then the cooperation need not limit the competitive advantages that can be sought and attained by any country. However, such scenarios and consequences are not possible to predict. The pace of the commercialization of fusion will probably be deliberate enough that appropriate competitive adjustments can be made along the way.

Will International Cooperation Reduce Our Costs?

The great article of faith is that it will reduce our costs, and that it will reduce everybody else's as well. The faith is held perhaps a bit more strongly among program administrators and finance officials than among technical people. There is a school of thought that thinks an international collaborative project would be more expensive than doing it within a single national program. The International Tokamak Reactor (INTOR) workshop, for instance, was asked, "What are the effects on cost and schedule of undertaking the INTOR project internationally and partitioning the detail design and fabrication of components, so each of the four parties could benefit from the development of all advanced technologies involved?" The consensus was that relative to a national project, such an international project would cost about 70 percent more, require a larger staff by about 15 percent, and would require about two years longer to complete. However, it is not clear that the question was asked in the right way. For instance, it is doubtful that JET, with many partners in the project, is costing 70 percent more than if it were, for example, totally a United Kingdom project. Nevertheless, true or not, if a major new machine is too expensive a project for any single national program, but can be managed financially by two or three collaborating together, then it does not matter if it is 70 percent more expensive because there is no other way to do it. In that case it is a bargain for each of the partners. That fact suggests that the answer to the question is not so much, "Yes, it will reduce our costs," as it is, "No, but it will allow us to maintain a broad program and to take significant steps forward without increasing our costs."

As to the next few years, there is little possibility that cooperation will produce large annual savings because EC and Japanese plans and budgets are committed to projects in train and thus unavailable for major new initiatives that might create significant savings.

Will International Cooperation Smooth the Way Towards
Acceptance by Utilities and the Public?

Yes, it will, for reasons given in the general incentives about acceptance. Again this effect works for the other partners in a collaborative effort equally well. There is, of course, no fundamental rule of nature that if everyone is marching in a certain direction, it is the right direction. Nevertheless, there is a strong momentum created by such a movement.

What Portion of the "Critical Path" to Fusion Energy
Is the United States Willing to Allocate to Cooperative Ventures?

Initially, only tasks at the margins of the national program will be offered up for cooperation because of the desire to maintain its strength. The same will be true for all the other partners. All will want full access and participation in all critical elements of cooperative projects that are established. That condition does not mean that there cannot be lead partners for particular parts of a machine in a joint enterprise. But it does mean that no single partner will be allowed to go off in his own laboratories and develop some critical piece of the technology without the full access and participation of staff from the other partners. As time progresses, the margins of cooperation can probably be widened as ways of equitably sharing results are developed.

What Degree of Project Management Is the United States
Willing to Yield?

After some internal debates, the United States will probably settle for dividing the management authority in a joint project approximately in proportion to investment. The EC and Japan, after similar processes, would probably arrive at the same results. This division would have to apply at levels corresponding to steering committees and on up to boards of directors. Any project that is actually going to be built ought to be headed by a single individual, and that means a single individual of one nationality or another.

RECAPITULATION

To recapitulate, this chapter has identified a number of factors at the level of policy that provide either incentives or constraints for expanded international cooperation in magnetic fusion. The incentives include promise of enhancement of needed technical progress, potential expansion of long-term economic benefits for each participant, possibility of saving cumulative development costs over the long term,

achievement of worthwhile political objectives, and broadening of fusion constituencies. Constraints are imposed by policies to preserve the strengths of the various national programs and to seek national prestige through technical leadership in fusion. No major short-term cost savings appear possible because firm plans in the EC and Japan will preclude any large-scale cooperative ventures over the next few years. Even so, taking into account the views of the groups who would be affected by expanded cooperation, the weight of the incentives prevails over the constraints. Thus, on balance, there are substantial potential benefits of large-scale international collaboration in the development of fusion.

TECHNICAL NEEDS AND OPPORTUNITIES

Within the worldwide magnetic fusion programs, a significant case can be made for international cooperation on the basis of maximizing the rate of progress by obtaining and sharing scientific and technical information. There is a long tradition of friendly competition and sharing in all basic science research, although as potential applications develop, access to information tends to get more restrictive.

In fusion, from the earliest days, there have been significant cooperative ventures. This chapter examines the broad technical characteristics of the magnetic fusion programs of the United States, the European Community (EC), and Japan to assess whether there are technical needs and opportunities suitable for cooperative efforts. The current status of the programs themselves and the record of past and current cooperation form the basis for identifying types of future possibilities that seem attractive, although it is left to those responsible for program definition to propose particular candidate projects.

Cooperation can take many forms but a reasonably complete listing consists of the following:

- o International meetings and conferences.
- o Personnel exchanges and joint research involving individuals or small groups.
- o Joint planning aimed at coordination of research and maximum use of facilities.
- o Joint programs on national facilities.
- o Cooperative design, construction, and operation of major facilities.

Technical needs for basic information, technology development, and major experimental facilities are covered in the discussions of the above categories.

STATUS OF THE PROGRAMS

The comparative status of the U.S., EC, and Japanese programs may be seen in broad perspective from Table 1. All are of comparable, although not identical, magnitude as measured by funding rates and personnel levels. The tokamak configuration is one of the mainline elements of the U.S. program and the only mainline element of the EC and Japanese programs. The second mainline effort in the United States is the magnetic mirror configuration. One or more of the alternative confinement concepts, such as the stellarator, reversed-field pinch, compact toroid, and bumpy torus, are being pursued in each program. The development of a number of advanced technologies, necessary for magnetic fusion energy, is being pursued most extensively in the United States and increasingly in the EC and Japan. These technologies include superconducting magnets, plasma heating by radio-frequency energy and energetic particle beams, and methods of safely handling the radioactive isotope tritium. Other technologies include the development of materials able to withstand both surface and bulk effects of a reacting plasma and the investigation of blankets to absorb the energetic neutrons that carry away the energy produced in the reacting plasma and convert it to a useful form. (See National Research Council, 1982, for further discussion of the above topics.)

In the United States, major program efforts are located in the laboratories of the U.S. Department of Energy (DOE), mainly Lawrence Livermore National Laboratory (LLNL), Plasma Physics Laboratory (at Princeton University), Los Alamos National Laboratory, Oak Ridge National Laboratory (ORNL), Argonne National Laboratory, Sandia National Laboratory, and Hanford Engineering Development Laboratory. In addition, the Massachusetts Institute of Technology and other major universities have significant programs. A major DOE-funded tokamak program is also located at GA Technologies, Incorporated, in San Diego, California.

The physics of plasma confinement will be studied using the existing Tokamak Fusion Test Reactor (TFTR) at the Princeton Plasma Physics Laboratory. Plans for a variety of follow-on machines, one of which is called the Tokamak Fusion Core Experiment (TFCX), have been discussed; but there is no commitment at present. Magnetic mirror confinement will be studied by the Mirror Fusion Test Facility (MFTF), under construction at LLNL. The pace of the U.S. program is to be determined by technical results, available resources, and perceived programmatic benefit.

In the EC the major installation, the Joint European Torus (JET), is located near Abingdon, in Oxfordshire, England. Work that is a part of the EC program is also being conducted by the United Kingdom at Culham Laboratory; by the Federal Republic of Germany at Garching, Karlsruhe, and Jülich; by France at Fontenay-aux-Roses, Grepoble, and Cadarache; and by Italy at Milan, Frascati, and Padua. Smaller activities are located in the Netherlands, Belgium, Denmark, Sweden, and Switzerland. The European program is managed as an entity by the

TABLE 1. Comparative Status of Magnetic Fusion Programs

Characteristic	United States	European Community	Japan
Approximate funding rate (\$ million per year)	440	370	300
Approximate number of professional personnel	2000	1000	1200
Mainline confinement concept(s)	Tokamak, mirror	Tokamak	Tokamak
Existing large machines	TFTR MFTF (under construction)	JET	JT-60
Proposed large machines	TFX (inactive)	NET	FER
Alternative concepts	Stellarator, reversed-field pinch, compact toroid	Stellarator, reversed-field pinch	Mirror, stellarator, reversed-field pinch, compact toroid, bumpy torus
Technology development	Superconducting magnets, r-f heating, neutral beam injection, materials, tritium, blanket, pellet fueling	Superconducting magnets, r-f heating, neutral beam injection, materials, tritium	Superconducting magnets, r-f heating, neutral beam injection, materials, tritium, blanket
Program direction	Department of Energy	Commission of EC	STA, Nonbusho, NITI
Role of universities	Small to medium projects	Small projects	Medium projects
Role of industry	Major supplier of components	Competitive supplier of equipment	Major supplier of components and systems
Principal program participants	National laboratories, universities, specific firms	Joint EC undertakings, national laboratories	National laboratories, universities

Commission of the European Communities, headquartered in Brussels. The work on JET and some smaller scale studies at the Joint Research Center of the EC, at Ispira, Italy, are joint activities of the member countries. (See Commission of the European Communities, 1984b.)

The broad intent of the EC program is to obtain from JET as much information as is possible about a plasma near the reacting level. Discussion and study is currently under way on the design of a machine called the Next European Torus (NET), which will use a deuterium-tritium (D-T) plasma reacting for a duration of more than 100 seconds per observation and which will test reactor-relevant technologies (NET Team, 1984). Finally a demonstration machine is contemplated to prove engineering feasibility.

The main line of the Japanese program is carried out by the Japan Atomic Energy Research Institute (JAERI), under the Science and Technology Agency (STA). It is this organization that is constructing and will operate the large JT-60 tokamak and investigate the associated technology (Japan Atomic Energy Research Institute, 1982). The Ministry of Education, Science and Culture (Monbusho, after its Japanese acronym) conducts a program of basic scientific and technological research in universities (Uchida, 1983). This program has funding comparable to the program of JAERI. The program investigates several confinement concepts including tokamak, tandem mirror, stellarator, reversed-field pinch, compact toroid, and bumpy torus. The Ministry of International Trade and Industry (MITI) is observing progress with interest, but so far MITI is not so heavily involved as the other two agencies. The program is coordinated through an advisory body, the Nuclear Fusion Council, reporting through the Atomic Energy Commission to the Prime Minister's office.

The long-term Japanese plans are to verify, using JT-60, the physics of confinement and the attainability of the necessary conditions of density and temperature in a hydrogen plasma for fusion to occur. Dependent on favorable results, planning is underway for a device called the Fusion Experimental Reactor (FER), to be constructed to study the operation and the technology associated with a fully reacting D-T plasma. Presumably some sort of prototype or demonstration will follow FER, but such plans are not definite at this time.

PRIOR COOPERATION

Research in the early days of fusion was classified, in the mistaken belief that success would come easily and great advantages would accrue to the first country to harness fusion power. The first major open exchange of information came in 1958 at a conference on the peaceful uses of atomic energy in Geneva. Following that conference, more normal kinds of scientific interaction appeared in the fusion

community. For example, the United States and the United Kingdom concluded an early agreement (Cockcroft-Libby) for cooperation.

One early example of experimental cooperation was the measurement of the electron temperature in an early Soviet tokamak by a British team. This measurement convinced the community that the tokamak configuration used by the Soviets was successfully improving plasma confinement.

There are also numerous examples of useful collaboration between the USSR and the United States in the area of magnetic mirror devices such as the invention of the "minimum magnetic field" configuration and the tandem mirror. These activities predated the 1973 Nixon-Brezhnev agreement on cooperation in nuclear energy and have continued. The U.S. fusion community went to considerable effort in 1983 to document the technical value of the U.S.-USSR cooperation and justify continuation of the agreement.

Interactions between the United States and the EC have also been extensive although quite informal in the sense of government-to-government agreements. There are, however, numerous instances of joint work and personnel exchanges, which were fruitful scientifically, especially on toroidal confinement systems, among them the stellarator and the reversed-field pinch.

Significant interaction with the Japanese has been more formal, with major activity following the agreement signed in 1979 on cooperation in energy research. Under this umbrella agreement, activity in joint planning, personnel exchanges, joint workshops, and even joint operation of facilities has flourished. These activities are discussed in detail in the following sections on present and future cooperation.

In fusion technology there has always been significant sharing of experimental and diagnostic technologies. In more recent years where specialized technologies such as neutral-beam heating of plasmas developed, there ensued international collaborations very similar to those on the scientific side. Typically the United States has been at the forefront in most of these areas, an exception being the gyrotron microwave source for electron cyclotron resonance heating, invented and developed in the USSR but perfected and made widely available by the U.S. program.

Other than interaction at meetings and personnel exchanges, the majority of technology collaborations has occurred under the auspices of international agencies. The International Atomic Energy Agency (IAEA) sponsors the International Tokamak Reactor (INTOR) study plus numerous meetings, workshops, and the scientific journal, Nuclear Fusion. The International Energy Agency (IEA), which includes the EC, the United States, and Japan but not the USSR, is the vehicle for the Large Coil Task (Haubenreich, 1983), the TEXTOR work, and considerable work in fusion materials.

CURRENT ACTIVITY

Meetings, Workshops, and Personnel Exchanges

International scientific and technical meetings abound in fusion and fusion technology under the sponsorship of numerous groups. Of the international agencies, the IAEA is particularly active. Its meetings and workshops, especially the biennial meeting on fusion, are one of the few vehicles for significant interaction with the Soviets.

Currently bilateral agreements exist, which formalize and balance the flow of people, between the United States and the USSR, and between the United States and Japan. In fact, outside of international meetings, nearly all of the U.S. interaction with Japan and the USSR is handled in a formal way, typically by agreeing once a year to a rather detailed agenda of cooperative activities. Additional interactions take place through normal scientific channels.

One activity that deserves special note is the INTOR workshop, which is a unique form of international cooperation midway between scientific workshop and a joint planning activity. The INTOR activity was originally formed as a consequence of a USSR proposal to look at the technical issues of designing and building the next step beyond the current generation of large tokamaks.

The cooperation involves teams from the United States, Japan, the EC, and the USSR. The mode of operation is national teams working on parallel tasks and meeting two or three times a year for several weeks in Vienna to critically discuss results and to plan future work. The activity was successful in identifying critical issues in both the physics and technology of fusion. Most people believe it is unlikely that the INTOR machine will be built, but a large number of significant insights have come out of the study. The approach is an excellent model for other activities.

Joint Planning

Currently, formal joint planning is restricted to an agreement with Japan. The major components are: (1) the program of the Joint Institute for Fusion Theory, a collaboration between the Institute of Fusion Studies at the University of Texas at Austin and the Institute for Controlled Fusion Theory at Hiroshima University; (2) joint planning in each of the principal science areas, namely, tandem mirror, stellarator, compact toroid, bumpy torus, and the JT-60 and TFTR experiments; and (3) a cooperative planning activity, which is part of a technology exchange, between the Japanese FFR design team and U.S. designers.

Informally, a great deal of joint planning, currently being formalized under the IEA, goes on between the United States, Japan, and the EC, primarily to coordinate experimental programs on the large

facilities. Coordination also exists between the U.S. and Japanese compact-toroid and bumpy-torus communities and between the U.S., EC, and Japanese reversed-field pinch experiments at Los Alamos, Padua, Culham, and various locations in Japan.

In technology there is growing coordination between the United States and Japan, particularly in material sciences; and cooperation is under discussion in a number of other areas. Most recently, in 1982, initial discussions, which have continued, have been held between workers in the United States and those in the growing EC technology program.

Naturally, the cooperatively operated facilities involve considerable joint planning. In addition, normal scientific interactions involve discussions that tend to coordinate technical programs either to avoid duplication or to verify important experimental or theoretical results.

Joint Programs on National Facilities

There are currently a number of national facilities with joint programs in the fusion program.

TEXTOR is a medium-sized, state-of-the-art tokamak in Julich, Federal Republic of Germany. Because of its excellent vacuum and plasma conditions and precisely defined and controlled plasma boundary, an international program in plasma edge science and plasma surface interactions has developed. The program is sponsored by the IEA; and involves experimental teams from the United States, Japan, and the EC. The facility is operated by the Germans, and the other teams generally build and bring their own experimental hardware. All results are shared so that each partner is spared the need of carrying on an equivalent effort alone.

The Rotating Target Neutron Source II (RTNS-II) is a high intensity dual (4×10^{13} neutrons/second) 14-million electronvolt neutron source at LLNL in the United States. The facility was built for DOE and is operated by LLNL. Because DOE was never financially able to operate both neutron sources, an agreement was reached with Monbusho to fund operation of the second source. Both partners share in the neutrons produced and the overall experimental program is jointly planned. All results are shared.

The Oak Ridge research reactors are funded jointly by the United States and Japan with a jointly planned radiation damage program similar in operation to the one at RTNS-II. Both are part of the U.S.-Japan bilateral agreement.

Finally, the Large Coil Task is an effort, organized under IEA, to operate, in a U.S.-funded central facility at ORNL, six large prototypical tokamak 8-tesla coils built by the partners. Three of the coils were built by U.S. firms and one each by the EC, Switzerland, and Japan. All design information and results are being shared.

Major Facilities

Currently only one major facility is jointly funded and operated. It is the Doublet III (D-III) tokamak at GA Technologies, Incorporated. An independent subagreement under the U.S.-Japan agreement on energy covers the collaboration, which comes under STA.

One of the principal purposes of the agreement was to give a Japanese physics team experience operating a large tokamak prior to the operation of the JT-60 machine in Japan. The cooperation is still active and has resulted in a vigorous and technically valuable program at D-III.

FUTURE COOPERATION

The technical justification and need for cooperation will continue to exist. If, as this committee recommends, more cooperation is to occur, even to the extent of substantial internationalizing of the program, such activities must make technical sense. This section covers some of the areas where cooperation, if increased, could have substantial impact toward improving the technical productivity of fusion. To be avoided, of course, is narrowing the focus of the program too soon or only seeking lowest common denominator solutions.

Meetings, Workshops, and Personnel Exchanges

Meetings, workshops, and personnel exchanges will continue to be of great importance even in a highly coordinated program. A coordinated program would provide increased breadth, so that useful cross fertilization between various concepts and various solutions to technology problems will occur.

In one case of a highly coordinated program, namely that of the EC, there is an efficient and formal mechanism to allow people to work temporarily in another laboratory. A worldwide coordinated program should also make such opportunities more widely available.

Joint Planning

Joint planning as a form of implementation of cooperation is discussed at greater length in the next chapter. It is assumed here that future cooperation will involve significant joint planning.

Potential Joint Projects

The technical success of joint activities up to the present is a major reason that this committee recommends expanded activity in the

future. Even though many of the present cooperations were not jointly planned as projects, the program has been jointly planned and technical results have been shared.

At the committee's domestic workshops and in its travels to Japan and Western Europe, many suggestions were made for joint activity consistent with technical needs. The rest of this section outlines the physics and technology areas where the committee feels cooperation is needed and technically justified. In many cases such as tokamak physics, multiple facilities with coordinated programs are required simply because of the amount and variety of information needed. In other areas like radiation damage or plasma surface interactions, one facility, or at most a few, would serve the international needs for data, just as accelerator and central computing facilities do.

In many ways, the EC program is a good model, within a given political framework, for a centrally planned and coordinated program with distributed facilities. A large-scale program coordinated among the United States, the EC, and Japan might adapt a similar model and procedures.

Physics

An obvious candidate for cooperation because of cost, is a large-scale tokamak with significant technology goals. Such a machine is envisioned in each of the programs with very similar goals and mission.

A number of additional tokamak facilities, each with different emphasis, are also needed to supply data in specific parameter regimes or for special purposes with limiter or divertor configurations. A coordinated program would plan activities at existing facilities or initiate new facilities at institutions where appropriate expertise or related facilities already exist.

In the alternative confinement concepts, a coordinated program could carry a greater variety of configurations to the proof-of-principle stage. Even programs with major facilities like the tandem mirror would benefit from coordinated scientific activity in other countries as well as from a joint program on the major facilities.

Technology

There are already a number of good models where joint programs reduce overlap, for example, TEXTOR, RINGS-II, the Oak Ridge reactors, and the Large Coil Test Facility, although this last project is not yet fully operational. Other technology areas which have been mentioned are:

- o A large-scale accelerated materials testing facility like the Fusion Materials Irradiation Test, proposed earlier but still lacking agreement.

- o Development facilities (cryogenics, background coils, and so forth) for very high field magnet development.
- o Neutral-beam and radio-frequency test stands.
- o Tritium-handling facilities.
- o Blanket-technology facilities.
- o Liquid-metal loops and experimental facilities.
- o High heat flux test facilities.

Another possible joint project, which has been highly successful in the United States, is a computer facility for large-scale plasma and facility modelling. Such a joint resource would similarly provide benefits to other large-scale world programs.

RECAPITULATION

There is sufficient similarity in the status of development and near-to intermediate-term objectives of the major world fusion programs to provide a technical basis for major international collaboration in the future. A long tradition of cooperation at the level of information and personnel exchange, gradually increasing to the level of joint programs on particular national facilities, shows that past cooperation provides a sound basis for future efforts. Instances of currently successful cooperation give confidence that larger cooperative efforts in the future would also be successful.

All the world programs have need for basic information in the physics of plasmas near fusion conditions; for the development of the numerous technologies necessary for fusion devices; and for the design, construction, and operation of major experimental facilities. Meetings, workshops, and personnel exchanges will continue to disseminate useful information about plasma science and the individual fusion technologies. In addition, larger-scale collaboration on joint projects in reactor-relevant physics and technology would also contribute to the solution of those technological problems. Finally, in designing, building, and using the major experimental facilities, there is ample opportunity for joint planning and joint undertakings.

AGREEMENT AND IMPLEMENTATION

The two preceeding chapters argue that incentives for a greater level of international cooperation outweigh the constraints and that there are many technical needs suitable for cooperation. It remains to examine those factors that will shape actual agreements for cooperation. Timing, compatibility of goals among prospective partners, stability in the partnership, and handling of technology transfer certainly rank high in importance. The list must also include net flow of funds from each partner into the cooperative projects, equitable sharing of benefits generated, suitability of the institutional framework, and workability of the actual management arrangements. Successful implementation of cooperative agreements will depend on the skill with which these factors are treated. Prior experience in many international cooperative enterprises shows that success can often be attained.

TIMING

If the time is not appropriate for some aspect of international cooperation, then it is unlikely to occur. There are stages, as national programs of research and development go on, at which particular collaborative efforts would be useful and appropriate. If the opportunities are missed and the programs get out of phase for such collaboration, at least one of the potential collaborators will find the prospect much less attractive.

A favorable opportunity for cooperation exists now because the three major world programs are at a stage of approximate technical parity, they face similar technical and budgetary problems for the next stage of development, competitive commercial rivalries are far in the future, and there is receptivity to cooperation at the political level.

More specifically, the time at which international cooperation on a specific project should be initiated depends upon the extent of the international cooperation. On the one hand, for a national project in

which foreign participation is sought at about the 10 percent level, it is probably best for the initiating nation to determine the objectives, cost, schedule, and design parameters of the project, with limited participation of potential partners. The initiating nation would then make a firm commitment to proceed and invite foreign participants to join in planning and executing the experimental program. On the other hand, for an international project in which the participants intend to collaborate as more or less equal partners, it is necessary for all to work together during the early determination of the objectives, cost, schedule, and design parameters of the project.

COMPATIBILITY OF GOALS

Differing levels of definition and detail in national fusion research and development programs can complicate negotiations on specific international cooperative projects. The party with the better defined program starts with the advantage of knowing more precisely where it wants to go and what it needs to obtain from the cooperative effort. The partners with the less well-defined programs are put at disadvantage. Their choice is between accepting an agreement that may not be fully advantageous or delaying the negotiation until they can evolve a suitable level of detail in their own national program plans to match that of the other negotiators.

The stated goals and milestones differ somewhat among the programs of Japan, the European Community (EC), and the United States, being more definite in the first two. Nevertheless, all these programs, to some degree, lack detail as to performance, schedules, and costs. This fact suggests the possibility, at least, of attaining a reasonable compatibility of goals through program adjustments.

Accordingly, two matters ought to be taken in hand soon by the U.S. Department of Energy (DOE). The first is the assessment of funding realities for the U.S. fusion program for some years to come, bringing the U.S. fusion community to recognize those realities, and the development in the U.S. fusion community of a consensus on the next important development steps to take. Without a generally accepted priority for the next development steps, all the different project proponents are in competition for the same funds. Until some agreement and order is imposed, these various groups of advocates could confuse any efforts at international cooperation rather badly. A key step in this process is an assessment, and the subsequent acceptance of that assessment, as to whether major machines of the future can be financed by the United States alone without crippling its base research and development program. Substantial increases over current budget levels would be necessary to support the major

machines. It if is concluded that those funding levels can and will be provided, then the U.S. fusion program will be strong on its own merits; and international cooperation becomes a voluntary matter of accepting foreign staff members and trading information. If the increased funding levels are assessed not to be available, then the fusion community will have to face that reality and come to agreement on other means, presumably international cooperation if that means is available, to progress toward the goal of workable fusion power systems.

The second matter that should go forward soon at the DOE is a more detailed plan for future research and development, particularly emphasizing the major machines and large development facilities that are anticipated to be needed and assigning relative priorities to each major component. Concrete near-term, intermediate, and long-term objectives and schedules for their attainment should be established. Such a plan would be valuable for several reasons. First of all, it would serve as a guide in defining the particular areas where the United States should seek international collaboration. Secondly, the inclusion of such major steps, as acknowledged components of the future U.S. program, would give all parties (including ourselves) a degree of confidence that an international agreement would actually be carried out. Thirdly, the plan would show more clearly whether the current array of basic program work and development projects is correct by placing them in their proper perspective in a hierarchy of needs. Finally, although the point is outside the province of this report, such planning enables a more efficient, better focused research and development effort. The plan, of course, should be displayed to the Administration and the Congress for review and concurrence.

STABILITY IN THE PARTNERSHIP

In order to enter into arrangements for international fusion cooperation, a certain degree of trust will be required among the participants. While trust is an initial prerequisite, the need for it continues from year to year. If it is ever lost, it is a quality extremely difficult to recover. It is important to avoid unilateral actions, perceived lack of support, and personal conflicts. Accordingly, a clear policy statement of the goals of the U.S. fusion program and a firm commitment to meet them would help establish such trust. It would be a mistake for the United States to try to compensate for a less than full commitment to fusion simply by increased emphasis on international cooperation.

In particular, once a medium- to large-sized project has been agreed upon, it is essential that the commitment to it continue during its life. This lifetime, of course, can cover a decade or two, a

circumstance that presents a problem in light of the annual budget review process that governments traditionally use. From time to time it is suggested that a project be taken "off budget" and, therefore, be not subject to annual budget changes. This move is never popular with legislators, who by such a process relinquish a certain degree of their jurisdiction. The arrangement is possible, however, where some independent fee, collected from users, provides money for such a fund--such as the automobile and truck taxes for highway funds. It is possible that such a fund could be established by utility users. It is also possible that through rather formal legal instruments, such as treaties, a strong obligation is created to support a project financially. The fact that international obligations exist will in themselves help to produce funding from year to year. However, the risk continues that at a certain time in the project life the budget resources needed will be terminated by one or more countries, leaving the remaining participants to complete the project on their own, a prospect that may not be acceptable or possible. Thus, the international instruments should address this question and, to the extent possible, produce a reliable supply of funds for the program.

Finally, there is the factor implicit in fairly widespread criticism abroad of the United States as a "reliable" partner in long-term research and development efforts. The annual appropriation process in the United States makes it difficult to guarantee continued support of a long-term commitment at the initially agreed-upon levels. Almost all U.S. commitments to projects in the past have been fulfilled, but a few have not, and those are remembered abroad. None of the people in fusion programs abroad visited by the committee suggested that this matter might preclude cooperation with the United States, but they cited reliability in the partnership as of high importance. Accordingly, in new cooperative ventures, all participants should take great care not to give new cause for complaint. The practice of identifying particular international projects explicitly in annual budget requests, clearly identifying the obligations implied for subsequent budget years, is one way to improve stability of funding.

TECHNOLOGY TRANSFER

Fusion technologies have both national security and long-term commercial implications. Therefore, cooperation in fusion impinges on not one, but two, critical technology transfer concerns. For purposes of this discussion technology transfer is considered to be the act of conveying know-how from one country to another. The means of doing so may embrace the export of technical data, equipment, and processes. Successful fusion cooperation could involve all three. U.S. interests are affected by technology transfers in several ways. These include:

(1) the strength of the domestic economy, (2) the competitive position in international markets, and (3) the complexion of political relationships.

Changing Attitudes

Historically, the United States has taken a relatively neutral position until recently on technology transfer, with the exception of transfers to the USSR and transfers of military technology in general. Most U.S. technology has been transferred across international boundaries through private trade and investment. In open international economic systems, it has been assumed that all nations are better off as a result of the transfers that occur. There is a changing perception, however, that one nation's technological gain is another's loss. Over the past several years the balance has shifted toward a more restrictive technology transfer policy and associated export controls, not only with the USSR but with our traditional trading partners as well. This perception complicates the argument based on mutuality of benefits for international cooperation in technical fields.

Technology Transfer with the European Community and Japan

The position of technological leadership held by the United States after World War II has faltered in many areas, and some have alleged an imprudent transfer of technology to our allies as the cause. However, the decline is the result of many factors that include the following:

- o Europe and Japan increased their national investment in research and development relative to gross national product; and the United States decreased its relative expenditures from 1965 through 1978, after which they began to rise again. Of course, in absolute terms, such U.S. expenditures considerably exceed those of other countries.
- o A greater proportion of all research and development has gone for military purposes in the United States than in Europe and Japan.
- o The two-way flow of much technological information, quite beyond the applicability of even the severest export control rationale, is normal and inevitable.
- o There has been an increasing demand in the United States for near-term results for research and development expenditures that has inhibited the accumulation of a base for long-term technological applications.

A fundamental tenet of our nation is freedom of communication. While there are recognized risks from the unrestricted flow of ideas and information, historically the benefits of such free flow, in areas where research and development continue to expand, have been much greater than the costs. Moreover, it is desirable to expand U.S. access to foreign technical information, including that available in Europe and Japan.

The foregoing points support our view that restrictions on transfer of fusion technology to EC and Japan are not likely to serve the purpose of maintaining the economic and political strength of the United States either in isolation or in its alliances.

As to actual articles, services, and technical data for magnetic fusion that are subject to export control through licensing, few items will be primarily related to defense. Even the number of products of strategic significance, including so-called dual-use items, is rather small. Examples of the latter are tritium technology, high-power millimeter-wave generators, advanced materials, and advanced robotics for remote maintenance. In potential instances of dual use a detailed examination and determination is made for each specific case. No denials of export licenses in magnetic fusion have yet occurred, but one cannot thereby conclude that no future limitations will arise. Nor is there enough information about the more restrictive trends to conclude that there will be a problem for certain. The matter will have to be faced as it arises, with the expectation of operating within whatever constraints are designed to safeguard the national security.

A second aspect of information and technology transfer works in the other direction. The U.S. Freedom of Information Act provides that, subject to a few specific exemptions, documents in the hands of U.S. government agencies are available upon specific request to members of the public. This circumstance may give pause to foreign partners who may be concerned that information developed in a cooperative venture and considered by them to be held for the sole benefit and use of the partners could be released by the U.S. side into the public domain. This matter is one to which some attention should be paid in the detailed provisions of the governing agreements, inasmuch as it has already surfaced, for example, in cooperation on breeder reactor research.

Recapitulation

To sum up the points made about technology transfer, fusion cooperation with the EC and Japan would be an instance of its advantageous aspects rather than its disadvantageous ones. To introduce constraints either for national security or commercial

reasons would be a severe and damaging step backward. The benefits of cooperation, far outweigh the associated technology transfer risks. The United States has much to gain from magnetic fusion cooperation and little technological leadership to lose.

Since the current substantial level of international cooperation and its associated flow of fusion research and development information do not seem to be unduly impeded by these limitations, future ventures in international cooperation presumably can also be arranged without unduly burdening them.

FLOW OF FUNDS BETWEEN PROGRAMS

Another aspect of implementation is the degree to which the funds of one country will be allowed to flow into cooperative projects. For the United States, if the financial contribution is to buy U.S. equipment and services that are contributed to the project overseas, then there ought not to be much difficulty aside from general budgetary constraints. Or, if the overseas project had an arrangement similar to that of the Joint European Torus (JET), with U.S. personnel part of the project staff and with good access to the information developed in the project, then again the only difficulty would be that associated with general budgetary constraints.

On the other hand, if the proposition is to send cash abroad to be spent by others in other countries for the overseas project, then one might expect the U.S. Congress to be reluctant to provide more than modest funds. Officials of the EC and Japan seem likely to take the same position. However as cooperation grows, more liberal attitudes should be encouraged so that funds might flow more easily in both directions with some latitude in the exact balance.

Nevertheless, investments in fusion projects of other countries can sometimes yield needed information and experience for far less money than would be required to produce that information and experience in the national program. The Japanese investment in Doublet III in the United States is a good example.

EQUITABLE SHARING OF BENEFITS

Benefits are of two kinds. The first kind consists of available staff positions in a joint project and amounts of design and equipment fabrication work to be done by contractors. The ancient rule of international collaboration is that one gets back in the form of these benefits a proportion approximately equal to one's share of the total investment.

Benefits of the second kind comprise the information and technological know-how and experience that flow from the project.

To an extent, technological know-how goes with having carried out design and fabrication for the project. These benefits, then, are distributed approximately in proportion to the investment of the partners. Information about how devices work and why they work, including information about technological details, is all carried away in the heads of the scientists and engineers who worked on the project as well as in the formal reports from the project. It is hard to measure and proportion what is in people's heads; and the partners will have to recognize in the beginning that, in terms of information benefit from the project, all partners who have competent staff on hand will share pretty much equally regardless of the individual financial investments.

As to the sharing of benefits, there exists a feeling in the EC that the Liquid Metal Fast Breeder Reactor cooperative program with the United States was unsatisfactory. The U.S. emphasis on trying to quantify an equitable exchange of information was frequently cited as a cause for the limited results of this cooperative effort. There are some indications that a similar emphasis may be inhibiting the creation of the necessary spirit of mutual trust and cooperation in current negotiations of cooperation in magnetic fusion.

Some of the benefits of the second kind will need to be captured through formal rights to intellectual property. However, patent policy and treatment of industrial proprietary information are areas of substantial difference in national style and practice. Before fusion moves to the position of commercial and industrial viability, it would be useful to reconcile the differences and establish those particular rights at an early stage. It may be possible at this moment to provide for cross-licensing and ownership of jointly developed information that would carry into the future. The effect on the motivation of industry as it may be affected by this treatment would need to be carefully analyzed.

INSTITUTIONAL FRAMEWORK

This section deals with some of the institutional options available for implementing international fusion arrangements that may be developed by the United States, the EC, and Japan or any two of the three. In time, international arrangements between nongovernmental organizations should be anticipated. However, currently and for the foreseeable future international fusion arrangements will probably be on a government-to-government basis because the high-risk, high-cost, and long-term nature of the endeavor puts the programs in the public sector.

Participants

Several possibilities exist as to participants in a fusion program, with each possibility having advantages as well as disadvantages.

International Atomic Energy Agency

The International Atomic Energy Agency (IAEA) has established a cooperative fusion program, which generally is considered to have been useful. The difficulty concerns the issue of cooperation between East and West because of current overriding political difficulties. Although this vehicle for near-term international cooperation is not currently viable, it should be kept in mind for the future, given that the attainment of economical fusion power is thought to lie several decades hence. If the political will should change so as to permit cooperation between the East and West on fusion, the IAEA could be an important organization bringing the parties together.

International Energy Agency

The International Energy Agency (IEA) is undertaking research and development projects in the fusion area as evidenced by the following agreements: "Implementing Agreement for a Programme of Research and Development on Plasma Wall Interaction in Textor," August 10, 1977; "Implementing Agreement for a Programme of Research and Development on Superconducting Magnets for Fusion Power," October 6, 1977; and "Implementing Agreement for a Programme of Research and Development on Radiation Damage in Fusion Materials," October 21, 1980. Certain countries interested in fusion such as France do not belong to the IEA, however, so that cooperation using the IEA framework could become more complex. On the other hand, the existence of IEA with its fusion program provides a ready international mechanism.

Bilateral and Multilateral Arrangements

The United States could have a bilateral arrangement with the EC and one with Japan. In addition, Japan and the EC could have a bilateral arrangement. This form has the advantage of direct relations between two parties so that the cooperation and management may be somewhat less complex. On the other hand, a major participant would not be included; and, if additional bilateral arrangements were established, in the end it might be more, rather than less, complex than a multilateral arrangement. The United States and Japan have a bilateral "Agreement on Cooperation in Research and Development in Energy and Related Fields," dated May 2, 1979. In accordance with this agreement, the two countries exchanged notes dated August 24, 1979,

establishing an agreement in fusion energy, and have exchanged further notes establishing committees and providing for cooperation in the Doublet III project. In addition, the EC and the United States are currently discussing a bilateral agreement.

The United States, the EC, and Japan could establish a multilateral arrangement that would involve all three groups. This form has the advantage of involving the principal participants in the West concerned with fusion, but it has the disadvantage of being more complex than a bilateral arrangement because of the number of participants.

Degree of Formality

Treaties

In almost all countries a treaty between nations is the most formal and binding agreement that can be established. Under U.S. law a treaty has the equivalent status of the laws enacted by the federal government. A treaty must be signed by the President and ratified by a two-thirds majority of the Senate. Nations consider treaties as important national commitments. Although a nation can abrogate its obligations under a treaty either by terms of the treaty itself or by unilateral action, the step is not taken lightly or often, affecting, as it does, the basic credibility of a nation. Because of the binding commitment contained in it, a treaty involves a greater degree of review than other forms of agreement and, therefore, normally takes substantially longer for its development and approval. On the other hand, once established, a treaty constitutes a mechanism for maintaining a high degree of certainty about the agreed position of the countries.

Heads-of-State Agreements

The Heads of State of seven major western countries and the EC, starting with the Versailles meeting of the Summit of Industrialized Nations and continuing through successive conferences, have endorsed in principle the idea of international arrangements on fusion. These commitments could be further implemented through heads-of-state agreements. However, the seven countries in the Summit include Canada, which has only a minor fusion program. The Summit tends to emphasize separate countries in Europe as opposed to the EC.

Although it is not out of the question that the Heads of State in the Summit could enter into an agreement, an alternative heads-of-state arrangement could be among Japan, the United States, and the EC or between any two of the three. Such an agreement carries the full weight of the government in power, although in the EC it would be necessary to ascertain its exact status. In the United States the agreement would normally be sent to the Congress for its information.

Abrogation of the agreement by a signing head of state would be an unusual, but not an impossible, act. On the other hand, succeeding heads of state could either confirm the previous agreement or disavow it. Even if the political parties change, there tends to be a certain degree of continuity from one government to another on matters that are more technical than political, as fusion would be for the foreseeable future. Thus, an abrogation of such agreement would not normally be expected, but the possibility would be greater than if a treaty were in force.

Ministerial-Level Agreements

A great many of the agreements between governments are negotiated and signed by appropriate ministries. While these agreements carry the full weight of the government's commitment, they are subject to changing governments as well as to the problems associated with funding through an annual budget process--an issue that is a problem with any arrangement.

Informal Government-to-Government Arrangements

Much information and many people can be exchanged without formal agreements. This opportunity results as a matter of policy decisions by governments to allow exchanges for which it is determined, for particular cases, that the best interests of all concerned can be served. These arrangements tend to be ad hoc, depending on case-by-case decisions, and, thus, work with a certain degree of flexibility. These informal arrangements also contain a degree of uncertainty as to whether they will be established or continued.

Scope of Arrangements

Umbrella Arrangement

An umbrella arrangement is usually a desirable instrument in that it establishes general principles and provides for certain activities immediately and authorizes others to be consummated at a later time. Thus, an umbrella agreement, after establishing the essential principles, could contain provisions for an immediate exchange of technology and personnel, authorize the formation of joint planning exercises, and provide for later entry into medium- and long-term projects. The advantage is that not all of the issues for the long term need to be decided; rather, a framework is established under which subsequent arrangements can be handled.

Base Program

It may or may not be possible to separate medium- and large-sized projects from a base program that is more research oriented. However, if such a division is possible, then cooperation on the base program could be established either in an umbrella agreement or in a separate arrangement. A base program should allow for a certain degree of flexibility, after consultation among all participants, since needs and priorities will change.

Medium- to Large-Sized Projects

While it is possible to put medium- and large-sized projects into an umbrella agreement, the latter ones, and possibly all of them, should be in a subsequent arrangement since they will be established over time. The principles under which medium- and large-sized projects are to be handled may be contained in the umbrella arrangement, but the actual details should be contained in a later arrangement. Once a medium- or large-sized project is agreed upon, then a high degree of reliability is required of all participants; and it is important to develop funding concepts that are viable for the term of the project. Since it is important to maintain these long-term commitments, the funding principles could be established in the umbrella agreement, subject to implementation in the project arrangement.

Joint Planning

Joint planning can proceed informally, reaching whatever consensus is possible and then relying for the residual matters upon decisions by individual nations or groups of nations. The approach would be to exchange information as to the plans all parties are undertaking but to leave all the participants to proceed according to their own particular goals.

On the other hand, joint planning can be more formalized, either in an umbrella agreement or as a subsequent arrangement, with whatever greater degree of binding effect may be agreed. To be effective, a formal joint planning activity would have to have policy guidance from government program leaders and technical direction from leaders in the laboratories. The undertaking should continue over many years.

At the program management level, the program leaders in the United States, the EC, and Japan should meet periodically to discuss and reconcile their respective programs for the development of fusion and to review the recommendations developed by joint planning groups in specific areas.

The joint planning groups should consist of a small number of the technical leaders from the laboratories in the respective areas. These groups should meet periodically to discuss material prepared at

home by a broader community of experts and should maintain continuity of participation. Laying the groundwork with the people in the field is crucial because it produces the worker-to-worker trust and confidence central to long-term success. The various programs already enjoy these advantages to a large degree because of the high quality of prior cooperative experience. It is also important that candidate projects for cooperation be proposed and justified by persons at the program level, since they are the best judges of the technical needs.

At present, it would be appropriate to establish two or three groups: fusion technology development; alternative confinement concept development; and, possibly, the next-step tokamak experiment. The first two groups would plan for collaboratively developing fusion technology and alternative confinement concepts, respectively. These tasks would include identification of the required information and facilities and recommendations for equitable sharing of costs, responsibility for construction and operation, and results. Cooperative projects successfully initiated at the smaller scale of plasma physics, alternative confinement concepts, and technology development will lay the basis for the larger-scale collaboration. If the United States does not plan to initiate a major next-step tokamak project within the next year or so, then it would be appropriate to establish a joint planning group for such experiments. This group would recommend objectives, conceptual design, schedule, and cost and would define the required supporting research and development. The International Tokamak Reactor (commonly known by its acronym INTOR) Workshop has shown that such tasks can be performed successfully by an international group.

Technical and Personnel Exchanges

There exist today extensive information and personnel exchanges, although sometimes there are some difficulties and restraints. These exchanges can continue to be handled as they are currently on a rather informal case-by-case basis, or they could be the subject of agreements contained either in umbrella or subsequent arrangements whereby procedures could be clearly established.

The experience of the JET Joint Undertaking has shown that, for exchanges or assignments of personnel for periods of months or years, it is quite important to provide international schools where the children of the staff may maintain the scholastic progress expected of them in their own countries. An equally important matter is to assure that workers may return home to equivalent employment at the end of their tours, without prejudice for having been away. Some Japanese officials expressed the wish that guest workers in Japan would try to enter more into its life and culture than they do now. By contrast, Japanese scientists temporarily working abroad usually make efforts to learn the language and to enroll their children in the schools of the new country even as they try to maintain their native culture.

WORKABILITY OF MANAGEMENT ARRANGEMENTS

Permitting Flexibility and Innovation

When a technology is in its early stages of research and development, it will become clear as results are obtained that new directions should be pursued and changes should be made in the current program. Thus, a process flexible enough to change with new technological information will in the long run make for a viable program rather than one burdened with outmoded concepts or unwise decisions. This feature, however, requires a careful structuring, since flexibility can also be the mechanism that produces unreliable partners. While there should be flexibility to change the priorities and program, it should be within the context of the agreement by the participants as opposed to unilateral action.

Site Selection

A frequent sticking point in large international projects is agreement on the site for substantial facilities. The JET project underwent great difficulty before its site, adjacent to Culham Laboratory, was settled. Keen rivalry for the site of the Next European Torus is already occurring. While site selection would normally occur on a case-by-case basis, it may be possible to spell out in the umbrella agreements the procedures and processes to be used in deciding on the location of facilities.

Partnership Shares

The extent of the participation of each of the partners is another factor subject to balance in establishing a cooperative project. Depending on circumstances, any degree of participation, from a junior role to full equality, may offer acceptable benefits. Obviously, the greater the degree of participation, the greater the voice that partner should have in decisions about the project's objectives, scope, approach, schedules, and cost, and the earlier that voice should be heard.

Practical Matters

A joint international project is complicated, but it can work if it is carefully planned and skillfully executed. Mechanisms must be established for creating an organizational entity and management structure. Procedures must be adopted for procurement, quality assurance, audits, and inspections. The authority of the project director, technical and political oversight mechanisms, national

funding contributions, and priorities for operation of the facility must be established. Policies with respect to national industrial involvement need to be debated and adopted. Legal instruments must define the relationship of the project to national and local governments, provisions for withdrawal, ownership of the facility, provisions for liabilities and insurance against risk, and provision for taxes and duties.

PRIOR EXPERIENCE

There are a number of successful international ventures. There is no model that one can follow except to recognize the complexity of such arrangements and to be willing to undertake the establishment of a system that matches the technology and the program's objectives. If there is any rule in this area, it should be that the institutional arrangements must match the problem.

Joint European Torus

For fusion the most relevant example of a major international project is JET (JET Joint Undertaking, 1982). The project was set up as a Joint Undertaking by the Member States of the European Community in 1978 (Wilson, 1981) under provisions of the 1957 Treaty of Rome, which established the European Community. Establishment of the Joint Undertaking was preceded by the JET Working Group, in 1971 and the JET Design Team, in 1973.

The following aspects of JET management (Commission of the European Communities, undated) are noteworthy:

- o The JET Council, assisted by the JET Executive Committee and the JET Scientific Committee, is responsible for the management of the project.
- o Each member of the Joint Undertaking is represented on the Council, usually by a individual from the policy level and another from the technical level.
- o The Commission of the European Communities is responsible for financial decisions to the extent of its 80-percent contribution to the project.
- o National research organizations provide guidance to the JET Council on technical issues.
- o The EC Council of Ministers, with the assistance of the Committee of Permanent Representatives, is responsible for political decisions.

European Organization for Nuclear Research

The European Organization for Nuclear Research (CERN) is another successful enterprise. Factors contributing to its success undoubtedly were its freedom from commercial stakes, freedom from military applications of its work, and absence of problems with the transfer of commercially useful technology. Evidently such an organization was the only way that European countries could mount a world-class program in high-energy physics of a stature comparable to that in the United States and to the program that promised to develop in the USSR and Iron Curtain countries. The governance of CERN has been highly successful and serves as a useful example of program and budget stability.

One unforeseen consequence of this large-scale international effort was that corresponding national programs of the member countries gradually diminished in size and impact. This effect may also occur in the EC fusion program as effort becomes concentrated on large devices. However, by that time, there may be less need for auxiliary national activities.

Fission Energy

Successful international cooperation has also occurred in the development of fission energy. Cooperation in this technology has proceeded at three different levels--that of information and personnel exchange, that of medium technology projects, and that of very large projects. The information exchange agreements have been fruitful, but they might have been more fruitful had they not been hindered by the recognized commercial applicability of the best technical information that was developed and by an excessive insistence on a quid pro quo in the exchange of such information.

Cooperation on medium-sized technology projects would have been enhanced if there had been better recognition of the relationship of the research and development that was being performed vis-a-vis its future commercial use and better provision for the capture of those benefits.

The Super-Phenix project, a 1200-megawatt (electric) fast breeder reactor, is an example of a large-scale project that probably could not have been conducted without international cooperation. Super-Phenix is the result of agreements between the French and Italian governments for breeder development signed in 1974 and agreements between the French and Germans in 1976 on three levels: an agreement on breeder development policy between the governments; an agreement on research and development and the "harmonization" of national efforts between the nuclear research agencies; and agreements on commercial development between French, German, and Italian companies.

Several factors seem to underlie the success of the Super-Phenix project (Beckjord, 1984):

- o The French provided strong project management and systems engineering on an extensive base of technology.
- o The French have majority control, and the other participants are junior partners. Management decision making was clearly drawn from the beginning, with lines of authority established from the utility customer to the reactor developer and designer and to the component manufacturers.
- o The commitment of the parties stems from their lack of indigenous fossil fuels and natural uranium, providing an imperative, as they perceive it, to develop breeder technology, which can make far more efficient use of natural uranium than can light water reactors.
- o There was a need to pool resources in such a large undertaking.
- o The Super-Phenix project developed against a background of other major cooperative efforts in Western Europe--in science, in aerospace and other multi-national business ventures, and in economic union--that served as trail markers.

Space Technology

In space technology the agreement between the United States and Japan as to the availability of space launch facilities is an example of limited international cooperation. The Apollo-Soyuz spacecraft rendezvous in orbit is an example of cooperation instituted by high-level political agreement. The actual conduct of that project illustrated the need for extremely detailed agreement on project management procedures when two countries of vastly different language and culture decide to cooperate. Current efforts of the U.S. National Aeronautics and Space Administration to obtain joint participation in the manned space-station project is another example of large-scale collaboration. This cooperative proposal has not developed far enough to provide any lessons for fusion; however, the space-station effort should be watched carefully for useful ideas.

International Telecommunications Satellite Organization

The International Telecommunications Satellite Organization (INTELSAT) is perhaps the most successful large-scale international venture in an institutional, operational, and commercial sense. Early on, a fundamental decision was made to reject bilateral agreements in favor of the multilateral introduction of satellite communications technology for global use in order to achieve its full benefits. Such a decision had to overcome vested interests in alternative modes of telecommunications, for example, undersea cables. Nevertheless, these

obstacles were overcome and a treaty-level agreement was concluded. Leive (1981) has identified a number of factors contributing to the institutional soundness of INTELSAT:

- o Phasing of successive agreements to proceed from the less well defined to the more well defined in order to defer hard policy choices until issues had matured and clarified.
- o Combining both political and technical interests in the governance of the organization.
- o Initial management by a strong national entity as agent for the organization followed by a deliberate shift to more truly international management as the organization matured.
- o Allocating financial interests and voting control to member countries in proportion to their use of the INTELSAT system.
- o Assuring that the benefits of new technology developed by the organization are available to its member countries for uses outside INTELSAT.

Jet Aircraft Engines

An example of international cooperation relatively far downstream in the life cycle of a technology was provided by the experience of a commercial firm in jet engines. In the experience of this firm, cooperation on a valuable commercial product was increased successively to greater and greater levels. Cooperation proceeded from the level of mere licensing to the levels of coproduction, shared production, and, finally, a joint venture, in which development engineering, manufacture, and marketing were shared. Such an experience may indicate that similar arrangements can be devised to capture the commercial benefits of fusion to the satisfaction of several cooperating entities.

RECAPITULATION

This chapter has examined some of the practical factors affecting the agreement and implementation of increased international cooperation, assuming that a policy favoring cooperation in principle has been adopted and that ample technical substance for such work exists. An opportune window in time for large-scale international collaboration is now open; if the timing were not favorable, even well justified technical initiatives would face resistance. The goals of the three prospective partners in collaboration either overlap enough or retain enough flexibility to initiate serious discussions of prospective joint activities. However, the first priority for the United States should be the establishment of a clear set of policies and objectives and a considered program plan for future fusion activities. Effective negotiations for increased cooperation need to rest on such a firm

basis. International collaboration will require stable international commitments to assure the long-term benefits contemplated by the collaboration and to avoid burdening the remaining partners by any reduction in support by one of them. Prior perceptions of unreliability, justified or not, may inhibit collaborative agreement unless overcome. Limitations on technology transfer constitute an external condition, imposed principally to safeguard national security. International collaboration in magnetic fusion would certainly be hindered by restrictive export control, but the outlook is that the regular case-by-case determinations will result in an acceptable situation.

Beyond these points, decisions specific to each case will have to be made about the net flow of funds among the partners; the use of existing institutional frameworks or the establishment of new ones; details of project management; and the capture of intellectual, industrial, and commercial benefits. In short, there is a host of considerations that must be resolved in the implementation, but all of these appear either workable or bearable, as the experience of many prior collaborative undertakings in diverse fields has shown. Consequently, given the intent to collaborate and the technical substance of it, satisfactory agreement and implementation should be achievable.

CONCLUSIONS AND RECOMMENDATIONS

In the course of its domestic workshops and its two overseas trips, the committee covered a wide range of topics concerned with international cooperation in the development of controlled, magnetically confined fusion. The study considered "cooperation," in the general sense of acting with others for mutual benefit on either a small or a large scale and "collaboration," in a somewhat more specific sense of working actively together as approximately equal partners in sizeable enterprises.

The various meetings identified three qualitatively different paths to fusion energy that lie open to the United States. The first is to support in a domestic program the full range of research, development, and prototype plant construction efforts that are needed to optimize the chances for successful fusion power generation, seeking all-out competitive advantage with respect to other world programs, simple parity with them, or somewhere in between. The second path is to carry out that sort of full-range program using increased international collaboration, which shares the financial costs and risks among several partners. The third is to accept a less-than-optimum domestic program, carried out at whatever level is affordable, accepting some likelihood that the United States would forfeit a greater or lesser degree of equality with other programs and, at the extreme, might have to purchase the technology from others sometime in the future. The middle path seems to the committee to be the preferable and practical choice. As a result, the United States would not, as on the first path, be mounting a more costly program than the competitive circumstances suggest. Nor would the country, as on the third path, be conducting a program more limited than it need accept. The committee believes, that, in time, potential partners will reach similar conclusions for themselves.

Accordingly, the committee expresses its view as an overall conclusion of the study:

- o For the United States in the years ahead, a program including increased international collaboration is preferable to a predominantly domestic program, which would have to command substantial additional resources for the competitive pursuit of fusion energy development or run the risk of forfeiture of equality with other world programs.

This conclusion is supported by several of the more specific ones presented below. The relevant conclusions concern the potential of greater benefits and lower costs (No. 1), the existence of an open window in time that implies feasibility (No. 2), the judgement that difficulties of implementation are either workable or bearable (No. 5), and the sound foundation provided by past cooperation (No. 6).

SPECIFIC CONCLUSIONS

1. On balance, there are substantial potential benefits of large-scale international collaboration in the development of fusion energy.

The benefits to be gained include a sharing of long-term, cumulative costs, diversification of risks, and a pooling of scientific and technical resources so as to enhance the needed results. In addition, both economic and political merit in cooperative efforts has been seen by participants in the Western Economic Summit meetings since 1982.

The factors at risk are mainly those associated with the prestige of the national programs, long-run commercial competitiveness that would follow from national program strength, and the undesired transfer of new technology. It should be possible either to contain these risks, by planning the nature of the collaboration, or to offset them, by realizing other benefits of the collaboration itself. The European Community itself is a current example of the net advantages of international collaboration.

* * * * *

2. A window in time for large-scale international collaboration is now open.

The United States, the European Community, and Japan have major programs in magnetically confined fusion that are, currently, similar enough in status and objectives to provide a technical and programmatic basis for future major collaboration. On the basis of

current planning and commitment either the European Community or Japan could achieve, at some date, a perceived position that would make international collaboration in a bilateral or trilateral mode less attractive to them than it is today. The Japanese have greater motivation to pursue fusion energy because of lack of indigenous energy resources; they are committed to make fusion a success as an energy source. The Japanese will consider collaboration, but only if it fits their independent program. The Western Europeans have already demonstrated collaboration at the international level through the European Community. The European Community attaches less urgency to its fusion program as a result of its anticipation of the fast breeder fission reactor. However, the European Community collaboration in fusion has overcome early obstacles and has generated a firm plan and stable support.

All our recent discussions revealed a desire for equal participation in planning, science, engineering, and management. At a more senior level, the people that we visited understood clearly the budgetary pressures for greater cooperation as well as the pressures of national interest. We found a receptivity to the idea of large-scale international collaboration at both the program leadership and political levels.

If one considers that each of the three major programs--in the United States, the European Community, and Japan--may well include an engineering reactor and a demonstration reactor (although the latter is not considered in the United States to be a government responsibility) as prerequisites to commercialization, there are also ample technical opportunities for large-scale international collaboration.

Finally, proprietary concerns are largely absent now because the programs are mostly conducted by the public sector in recognition of the long time before commercial application is likely.

* * * * *

3. Large-scale international collaboration can be achieved, but not quickly.

Because both European Community and Japanese planning is detailed and resources are rather firmly committed for the next few years, large-scale collaboration does not appear possible before the late 1980s. Moreover, results from the Joint European Torus and the JT-60 tokamak in Japan, as well as from the Tokamak Fusion Test Reactor, will also become available during this period; and important program choices are awaiting this information.

Furthermore, any major collaboration must meet the requirements of the separate programs of the parties and so must be preceded by a joint planning effort.

Therefore, while major collaboration may offer investment savings, as well as less risk and a superior program, such results can be expected only after a suitable lead time has elapsed for putting the mechanisms into place.

* * * * *

4. International collaboration will require stable international commitments.

There are a number of nontechnical factors that could inhibit large-scale international collaboration unless overcome. The United States is perceived as being an "unreliable partner" based on previous experiences in space sciences, synthetic fuels, and, to some extent, fusion itself. There are also perceptions of the United States as not having a firm commitment to develop fusion, nor of having a sound development plan. U.S. policy considerations that go beyond fusion may constrain the options for collaboration. The annual funding appropriation process makes a multiyear project appear as a high-risk venture. By contrast, the European Community operates with a five-year budget and program plan revised every third year.

Futhermore, U.S. fusion policy is perceived to change much more frequently than that of either the European Community or Japan. U.S. directions--enunciated by the Magnetic Fusion Engineering Act of 1980, the more recent Comprehensive Program Management Plan of 1983, and the Energy Research Advisory Board recommendations of 1983-1984, together with current debate, which appears not yet to have coalesced into policy--all of these are observed closely by our potential partners and result in confusion abroad. Past programs outside the responsibility of the U.S. Department of Energy have exacerbated this perception of the United States.

There are, however, successful precedents for stable international commitments: the European Organization for Nuclear Research, the International Telecommunications Satellite Organization, and the Joint European Torus (JET) Joint Undertaking. We believe the Joint European Torus experience, especially, provides an illuminating example.

Since substantial benefits from international collaboration would materialize only from a relationship that was sustained over the long term, some form of agreement will be required that gives all partners a high degree of confidence that each will carry out its commitment without creating a burden on the others by withdrawal of participation and support.

* * * * *

5. There is a host of considerations that must be resolved in implementation, but these appear workable.

In pursuing international collaboration as the preferred course of action, the many complexities that are inherent must be recognized and dealt with. Failure to consider the following in a timely fashion can lead to real difficulty:

- a. The fragile balance between independence and interdependence.
- b. A procedure for site selection for major future devices.
- c. The impact of perceived commercial value, as exemplified by current restricted access to fast breeder reactor engineering technology.
- d. Ownership or sharing of intellectual property.
- e. Policy with respect to licensing technology to nonparticipants.
- f. Equitable participation by industry, including consideration of differing tax and subsidy policies.
- g. The question of technology transfer in instances where national security is considered to be involved.
- h. Acceptance of international standards, particularly for safety and radiation.
- i. The impact on established domestic institutions, such as the national laboratories; some changes in roles and missions seem inevitable.

The committee believes, however, that none of these factors represents an insurmountable obstacle. Satisfactory management arrangements internal to the undertaking can probably be devised, and limitations external to it can probably be borne. Each issue may be addressed when it arises.

* * * * *

6. Past cooperation provides a sound basis for future efforts.

It was clear from the courtesies extended, from the hours of talent invested in the discussions with the committee, and from the open and frank exchange of views that past international relationships in the fusion community have been excellent. A high degree of mutual trust and respect prevails among leaders of the several programs. Furthermore, there is a precedent of generally successful international cooperation on a modest scale in fusion. These precedents include long-standing information and personnel exchanges, the bilateral agreement between Japan and the United States, the trilateral agreements under the International Energy Agency, and the workshops on the International Tokamak Reactor. We believe that this background provides reason to be optimistic about the possibility of successful achievement of the general goals established at the recent Economic Summit meetings of Heads of State.

RECOMMENDATIONS

Having concluded that large-scale international collaboration is the preferable course, the committee makes two recommendations to proceed:

1. The first priority should be the establishment of a clear set of policies and objectives and a considered program plan for future U.S. fusion activities.

Concrete near-term and intermediate objectives and a schedule for their attainment should be established by the U.S. Department of Energy and displayed to the Administration and the Congress for review and concurrence. Such information is a prerequisite for substantive discussions with potential partners as well as the basis for long-range international commitments.

Improved means should be devised for satisfying Congressional oversight and budget control and at the same time providing improved program stability. As a minimum, multiple year contracts and carefully controlled off-budget financing could help.

Inasmuch as large devices are prime candidates for international collaboration, the United States should promptly formulate its position with respect to next-generation tokamak experiments relative to the Next European Torus in the European Community and the Fusion Experimental Reactor in Japan. If the positions overlap, the United States, as part of the recommendation made below, should explore collaboration with the European Community and Japan in all phases of planning, constructing, and operating a next-step tokamak.

* * * * *

2. Having carried out the preceding recommendation, the United States should take the lead in consulting with prospective partners to initiate a joint planning effort aimed at large-scale collaboration.

The inevitable lead time associated with large-scale collaboration calls for initiatives to be started earlier rather than later.

Initial assumptions should recognize that the program of the United States, as well as those of the European Community and Japan, must start from a self-sufficient base. The planning effort should identify first those areas where the national and regional plans have coincident interests. Successful cooperation on a smaller scale will lend confidence to larger undertakings. Steps that would lead to interdependence must, as a practical matter, come later. These steps may produce a reasonable compatibility of goals for major experimental fusion devices in the period following the completion of various firmly committed, near-term projects.

This activity should be endorsed at political levels and steered by the fusion program leaders in the respective countries, who should meet periodically to reconcile their programs. Subsidiary planning groups, involving technical leaders, should meet periodically to plan cooperative activities. This activity must be a continuing one. The involvement of the technical level is important both to the planning of sound objectives for the project and to the development of a cooperative spirit for its pursuit. It seems self-evident that the United States should not advocate in these meetings what it cannot deliver.

Although the United States, the European Community, or Japan might well take the lead in proposing increased collaboration, the committee believes that, because the United States is currently reexamining its program, the initiatives could be taken with greater ease from this side. There is, here, an opportunity to provide leadership in a uniquely important technology development of global significance as a potential power source, provided that recognition is given to the concept that leadership is possible in a partnership if we are willing to share it.

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*The references are limited to those of special relevance or interest. The report covers a wide range of topics, either based on our workshops and trips or commonly known by persons following the field. Thus, a comprehensive list of references, in the first instance, does not exist and, in the second, is unnecessary.

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APPENDIX A

SCOPE OF WORK*

A [Committee] on International Cooperation in Magnetic Fusion will be established consisting of approximately ten members with broad backgrounds in electrical engineering; plasma physics; fusion technology; fusion reactor design; industrial participation in high-technology projects; energy supply; technology transfer; and the legal, diplomatic, and political aspects of multinational governmental ventures. The [committee] will:

- A. Identify the most important issues in international cooperation in magnetic fusion energy, so that they may be addressed in the study.
- B. Review and discuss alternative courses of cooperation in view of the scientific, technological, and engineering needs of fusion power, these courses being consistent with the areas of greatest competence of participating countries and with reasonable assumptions about future technological progress and international relationships.
- C. Review U.S. goals and objectives for the development of magnetic fusion as they may be phased over time and as they may relate to technological progress, industrial involvement, and selected socioeconomic factors. Compare U.S. goals and objectives with corresponding ones that may be available for the European and Japanese fusion efforts, in order to identify similarities and differences.
- D. Identify and characterize long-term implications of various courses of international cooperation with respect to U.S. goals, drawing as necessary on experience with other instances of international scientific and engineering cooperation.
- E. Recommend courses of future international cooperation as to technical topics, experimental facilities, extent, duration, and structure, drawing as necessary on prior studies.

*Excerpted largely from the Notice of Financial Assistance Award from the U.S. Department of Energy to the National Academy of Sciences.

- F. Obtain the views of leaders of the U.S. and foreign fusion communities on the matter of benefits already realized from international cooperation in magnetic fusion energy and benefits expected from enlarged cooperation.
- G. Provide an interim report on the progress in formulating recommended U.S. courses of action and the underlying reasons; incorporate the results of the whole study into a final report.

The committee will plan and conduct invitational workshops to consider courses of technical cooperation, goals and implications. The workshops will allow full exploration of alternatives while preserving the prerogative of the sponsor to develop U.S. positions.

APPENDIX B

SUMMARY OF DOMESTIC WORKSHOPS

Two domestic workshops were conducted to explore viewpoints within the United States on the opportunities, policies, and arrangements bearing on a qualitatively higher level of international cooperation in the development of magnetic fusion energy. The salient views as expressed by the workshop participants are summarized here. These views were considered, but not necessarily adopted, by the committee in reaching its conclusions. For convenience, each workshop is described separately, in approximate correspondence with its topical sessions.

FIRST WORKSHOP

The agenda for the first workshop is shown in Figure 1.

Technical and Programmatic Considerations

In the past the United States has gained substantial technical benefits for its magnetic fusion program from international cooperation. Foreign fusion programs have scientific, technical, and engineering strengths in many areas that are comparable, if not superior, to those of the United States:

- o Japan--solid breeding materials, superconducting magnets, materials, neutronics, engineering design.
- o European Community (EC)--liquid breeding materials, superconducting magnets, materials, plasma-wall interaction, tokamak physics, stellarator physics, tritium, reversed-field pinch physics, nuclear technology, radio-frequency heating technology.
- o Soviet Union--plasma-wall interaction, superconducting magnets, tokamak physics, tandem-mirror physics, radio-frequency heating technology.

NATIONAL RESEARCH COUNCIL
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AGENCY ENGINEERING BOARD

Committee on International Cooperation in Magnetic Fusion
WORKSHOP ON INTERNATIONAL COOPERATION IN MAGNETIC FUSION
FIRST WORKSHOP

Joseph Henry Building
2100 Pennsylvania Avenue, N.W.
Washington, D.C.
December 14-15, 1983

PURPOSE: To explore the opportunities, policies, and arrangements bearing on a qualitatively higher level of international cooperation in the development of magnetic fusion energy.

AGENDA

Organized by Weston M. Stacey, Jr.

Wednesday Morning, December 14

SESSION 1. BACKGROUND. J. Gavin, Session Chairman

Purpose and Scope of the Workshop	Joseph Gavin
Status of Magnetic Fusion	John Clarke
Program Plans of European Community, Japan, and USSR and Existing International Cooperation	Michael Roberts

SESSION 2. RELEVANT EXPERIENCE. A. Morrissey, Session Chairman

Joint European Torus (JET)	John Sheffield
Large Coil Test Facility	Paul Haubenreich
International Telecommunications Satellites	John McLucas
United States-Japan Space Launch Agreement	Norman Terrell
United Technologies' Experience in International Cooperation in the Jet Field	James Bogard

The National Research Council is the principal operating agency of the National Academy of Sciences and the National Academy of Engineering to serve government and other organizations

FIGURE 1 Agenda for first workshop.

Wednesday Afternoon, December 14

SESSION 3. TECHNICAL BASIS FOR COOPERATION IN PLASMA PHYSICS, BASIC TECHNOLOGY, AND COMPONENT DEVELOPMENT. R. Borchers, Session Chairman

Possibilities of Further Cooperation in Plasma Physics and Basic Technology	Robert Conn
Large Test Facilities Needed for Component Development	Charles Baker
Panel Discussion on Technical Considerations for Cooperation in Plasma Physics, Basic Technology, and Component Development, Distinguishing Among the Three Major Overseas Programs	Robert Borchers (Panel Chairman), Charles Baker, Harold Furth, Gerald Kulcinski

SESSION 4. TECHNICAL BASIS FOR COOPERATION ON LARGE FUSION PROJECTS. D. Kerr, Session Chairman

Anticipated Large Fusion Projects	John Gilleland
Panel Discussion on Technical Considerations for Cooperation on Large Fusion Projects, Distinguishing Among the Three Major Overseas Programs	Donald Kerr (Panel Chairman), Robert Conn, John Gilleland, Melvin Gottlieb, Norman Terrell

Thursday Morning, December 15

SESSION 5. POLICIES ON INTERNATIONAL COOPERATION. J. Hendrie, Session Chairman

Panel Discussion on the Objectives, Constraints, Long-Term Implications, and Political Acceptability of International Cooperation, Distinguishing Among the Three Major Overseas Programs	Joseph Hendrie, (Panel Chairman), James Bogard, Richard DeLauer, Jack Dugan, Bryan Lawrence, Robert Uhrig
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FIGURE 1 Agenda for first workshop (continued).

SESSION 6. IMPLEMENTATION AND ORGANIZATION. M. Muntzing, Session Chairman

Legal Instruments of Agreement for International Cooperation	Susan Kuznick
Organization and Administration of International Projects	George Cunningham
Panel Discussion on the Role of Government and of Industry in International Projects, Distinguishing Among the Three Major Overseas Programs	Manning Muntzing (Panel Chairman), George Cunningham, Gerald Helman, Susan Kuznick, David Leive, John Moore

Thursday Afternoon, December 15

SESSION 7. SUMMARY. W. Stacey, Session Chairman

Conclusions from Sessions 3-6 with Emphasis on Implications. Discussion.	Robert Borchers, Donald Kerr, Joseph Hendrie, Manning Muntzing
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FIGURE 1 Agenda for first workshop (continued).

At the most modest level of cooperation, the free and informal exchange of basic scientific and technological information that now exists is valuable to the U.S. program and should continue to be encouraged. The only government action required is merely to insure that no impediments to free information exchange are created.

Organized cooperative efforts, in which each side pays its own way, should be further encouraged in order to make the most efficient use of available resources worldwide. This category includes the following activities:

- o Joint planning of national research programs in specific areas for complementarity--for example, the joint planning of materials research under the International Energy Agency (IEA)--and a sharing of results.
- o Joint studies, such as the International Tokamak Reactor (INTOR) under the International Atomic Energy Agency (IAEA), that focus effort on critical technical issues and identify research and development needs.

At the next level, participation of one or more nations in a technology test facility, a component development and test facility, or a plasma physics experiment of another country could reduce the number of such facilities needed worldwide. Examples of each type of facility are, respectively, the Fusion Materials Irradiation Test (FMIT) facility, the Large Coil Test Facility (LCTF), and the TEXTOR tokamak. It would be easier to establish an equitable cost for participation on a case-by-case basis, rather than attempting to establish a comprehensive agreement encompassing many cases. However, an umbrella agreement that provided for the possibility of several individual cases would be appropriate.

The highest level of cooperation, in terms of both degree of international collaboration and complexity of organization, consists of an international project--such as Joint European Torus (JET). Truly international projects are appropriate only for major facilities, such as the suggested Tokamak Fusion Core Experiment (TFCK) or Engineering Test Reactor (ETR), because of the great amount of negotiation that will be required for their establishment.

Examples of International Fusion Cooperation

An open and informal exchange of scientific information through publication, meetings, and visits has existed among the major fusion nations since 1958, when the subject was declassified. The U.S. exchange with Western Europe has been the most extensive.

There is a formal agreement for exchange of personnel for short periods of time with the USSR.

Formal cooperative agreements with Japan exist in several areas: personnel exchange, joint research and development planning in seven

areas, joint institutes for fusion theory, Japanese utilization of the Doublet III tokamak experiment for about \$10 million per year from Japan, and Japanese utilization of Rotating Target Neutron Source II (RTNS-II) for about \$1.8 million per year from Japan.

There is formal cooperation through the IEA under an umbrella agreement in three areas:

- o Japan and the EC use the LCTF to test their magnets (Haubenreich, 1983).
- o The United States and other countries perform plasma experiments in the TEXTOR tokamak of the Federal Republic of Germany.
- o There is coordination of planning for materials research and for research on large tokamaks.

There is formal cooperation with the EC, Japan, and the USSR to focus effort on critical technical issues for next-generation tokamaks and their supporting research and development in the INTOR Workshop.

Policy Considerations

The official goals of the U.S. magnetic fusion program, as embodied in the Comprehensive Program Management Plan (CPMP) (U.S. Department of Energy, 1983), were discussed and were thought to be ambiguous in some respects and to fail to convey a firm commitment to the development of fusion power. There are significant implications of this policy for increased international cooperation:

- o The pointed implication of the CPMP objective "to maintain a leadership role" is that the United States has not adopted a national policy to be the leader. Other nations will be much more anxious to cooperate with the leading program than with one that is even with or behind their own.
- o The CPMP also states an intention "to maintain this position [of leadership] in the two major confinement concepts...through a carefully formulated and managed policy of close international cooperation to share specific tasks." The implications of this statement are that all essential elements of the mainline effort will be retained within the U.S. program, that the United States will cooperate with other countries only in areas in which they are in a leading position, and that hard bargaining on the part of the United States over equity in technical and financial contributions will be a feature of all negotiations. This is not a posture that is likely to foster a spirit of cooperation.
- o The goal of the U.S. program, as stated in the CPMP, "...is to develop scientific and technological information required to design and construct magnetic fusion power systems." This goal

does not contemplate the development of an industrial base for the fabrication of engineering components or the construction of either a demonstration or prototype power reactor; rather, these tasks are left to industrial initiative. Since the other major fusion nations seem to consider the goal of their programs to be the development of fusion power through the demonstration reactor stage, including engineering component development, there is a possibility that this incompatibility of goals could inhibit the development of cooperative agreements.

- o The Japanese, EC, and USSR program plans in magnetic fusion call for engineering test reactors of roughly similar objectives and characteristics. The devices are designated as Fusion Engineering Reactor (FER) in Japan, Next European Torus (NET) in the EC, and OTR in the USSR. These reactors would be built during the 1990s, followed by a demonstration reactor. The U.S. program plan, as contained in the CPMP, also calls for a similar machine, ETR, to be planned during the later 1980s. However, recent budgetary constraints have caused planning at the technical level, as of the time of the workshop, to be directed towards a less ambitious next step, TFCX, which embodies the physics of ETR but few of the technological and engineering testing features.

A clear policy statement on the goals of the U.S. fusion program and a corresponding firm commitment to meet those goals is a prerequisite for establishing international cooperative projects on a major scale. It was noted that one of the principal reasons for the success of the French Super-Phenix project was a clear national policy that assigned the project high priority, strong technical and industrial support, and adequate financial support. It would be a mistake for the United States to try to compensate for a half-hearted commitment to fusion with increased emphasis on international cooperation.

Broader U.S. policy considerations may be at odds with technical opportunities for cooperation:

- o The USSR has officially proposed the design and construction of the next major tokamak experiment on an international basis and has informally expressed a willingness to see this device sited in Western Europe. Administration policy and Congressional inclinations are negative towards cooperation with the Soviet Union now, but this position could be reversed if East-West relations change.
- o Japan would probably welcome the opportunity for further cooperation with the United States on engineering component development and major fusion projects. Congress would probably be reluctant to endorse such cooperation because of political sensitivity to Japanese incursions into U.S. markets and the

impact of technology transfer upon U.S. technological leadership.

- o The countries of the EC believe that leadership in magnetic fusion research lies in Europe in the near future and are skeptical of the reliability of the United States as a partner because of past experiences; consequently, the EC presently shows little inclination to cooperate on major new projects. On the other hand, cooperation with EC would probably be acceptable to Congress; and the technology transfer issues would be easier to resolve.

The extent of reliance on international cooperation to achieve the objectives of the U.S. magnetic fusion program is a key policy issue. There are two aspects of the issue:

- o Should the United States rely on cooperation with programs abroad, where they are or may become available, to carry out technology development or to investigate plasma physics questions in areas that are vital to the mainline U.S. program(s)? The past practice has been not to do so, but rather to encourage foreign program leadership in areas considered less vital. This position is quite probably unsatisfactory from the viewpoints of other countries.
- o Should the United States require early joint planning, in the hope of achieving collaboration with programs at home for major new component test facilities and fusion experiments? It seems more likely that foreign collaboration could be established after a firm commitment to go forward with a project had been made by the United States, although there are good reasons to involve prospective partners in early planning.

One compromise on the first point would be to minimize the effects of duplication of effort by phasing related efforts in time among the several partners, rather than asking any partner to forgo an important line of work entirely.

In three policy areas conditions on technology transfer arise in the implementation of cooperative projects: national security, protection of the economic interests of U.S. industry, and preservation of advantage to foreign participants from technology developed by them in the face of provisions of the U.S. Freedom of Information Act mandating public access to such information.

Implementation and Management Considerations

There appear to be many possible methods of implementation of international cooperative arrangements: treaties, Executive agreements, intergovernmental agreements, and bilateral purchase contracts. Treaties establish the most binding commitments of the

U.S. government, but they are the most difficult to establish. Intergovernmental agreements are much easier to put into place because they can be negotiated at lower governmental levels, but they are also much less binding--they can be unilaterally terminated. The credibility of the United States as a "reliable partner" has been damaged by past unilateral terminations in space sciences, synthetic fuels, and even fusion itself.

Existing international organizations offer auspices under which more extensive international cooperation could be carried out without the necessity of new implementing agreements. As previously noted, the IEA is currently serving quite effectively as a mechanism for the participation of several nations in LCTF and TEXTOR. The INTOR workshop under IAEA was also mentioned above. An expansion of such activities under these agencies is reasonable. However, neither IEA nor IAEA, or indeed other existing international organizations, would be suitable as sponsors for a major international project because they all are primarily coordinating, rather than managerial, organizations.

Still, an existing international organization may provide a framework for initiating a project, as was the case with the European Organization for Nuclear Research (CERN). CERN was initiated by an organizing conference in 1951, sponsored by the United Nations Educational, Scientific and Cultural Organization, in an action that was ratified three years later by enough countries to assure 75 percent of the required funding. CERN went on to become a highly successful institution, with international participation in design and construction of large-scale facilities and in performance of experiments.

For fusion the most relevant example of a major international project is JET (JET Joint Undertaking, 1982). The project was set up as a Joint Undertaking by the Member States of the EC in 1978 (Wilson, 1981) under provisions of the 1957 Treaty of Rome, which established the EC. Establishment of the Joint Undertaking was preceded by the JET Working Group in 1971 and the JET Design Team in 1973. Failure in the initial agreement to create a mechanism to decide on the site almost resulted in cancellation of the project in 1977.

The following aspects of JET management (Commission of the European Communities, undated) are noteworthy in that they combine technical and political elements in the decision-making chain:

- o The JET Council, assisted by the JET Executive Committee and the JET Scientific Committee, is responsible for the management of the project. The Council meets at least twice a year.
- o The Commission of the European Communities is responsible for financial decisions to the extent of its 80-percent contribution to the project.
- o National research organizations provide guidance to the JET Council on technical issues.

- o The EC Council of Ministers, with the assistance of the Committee of Permanent Representatives, is responsible for political decisions.

The International Telecommunications Satellite Organization (INTELSAT) provides a relevant example of the principle of "phasing in" an international project. Rather than attempting to define a complete set of international agreements at the outset, INTELSAT was established on an interim basis. The agreement specified a time period for a study of the permanent form of the organization but did not set a deadline for the end of the interim arrangements. The permanent INTELSAT agreement, which was concluded six years later, provided for a phased shift from management of its space operations by the United States, as agent, to truly international management.

The following features of INTELSAT management are noteworthy as to the combination of technical and political elements:

- o The Assembly of Parties, which meets every two years, is composed of all nations party to the Agreement and is primarily concerned with issues of concern to the Parties as sovereign states. The principal representation is provided by foreign ministers.
- o The Meeting of Signatories, which meets annually, is primarily concerned with financial, technical, and program matters of a general nature. The principal representation is provided by the appropriate technical ministry.
- o The Board of Governors, which meets at least four times a year, has responsibility for decisions on the design, development, establishment, operation, and maintenance of the international portions of the system. The principal representation is provided by officials concerned in their home countries with the operation and management of the system.
- o Several advisory groups expert in technical, financial, and planning matters assist the Board.

INTELSAT provides an example of finance and control in an international project. Each member's financial interest and voting share on the Board of Governors is strictly proportional to its use of the system, determined on an annual basis; and the member is required to contribute that proportion of the incurred costs.

The ICTF provides an example of finance and control in a national project with international participation. The United States funds, constructs, and operates the facility and pays the costs of its own test coils. The other participants pay for their own test coils. An executive committee, with one representative from each participant, decides on the test program.

The annual appropriation process makes it difficult for the United States to commit to multiyear projects without the possibility of

facing a choice later of either renegeing or sacrificing other elements of the fusion program.

Another limitation on the implementation of cooperative projects is to be found in conditions on the flow of money between the United States and foreign collaborators. For example, will the United States be willing to contribute money to construct a major facility sited in another country?

Finally, emphasis by the United States on equity and quid pro quo in current negotiations may be inimical to creating a spirit of mutual trust and cooperation.

To sum up, the success of any international cooperation depends upon the extent to which technical considerations and political requirements can be merged. Although previous experience can provide guidance, the appropriate implementation structure must be specifically designed for the project at hand.

SECOND WORKSHOP

The agenda for the second workshop is given in Figure 2.

Technical and Programmatic Considerations

Fusion is viewed in most quarters as a potential energy resource and therefore as a technology that is important to develop. However, there is not a general recognition of a clearly defined goal of the development program. For example, one participant suggested that the world may pass over the fission breeder and go directly from the light water reactor to fusion; but the fusion program does not take such eventualities into account. Without clearly defined program goals, it becomes hard to use international cooperation as an effective means of reaching them.

Nevertheless, a recent report of the Magnetic Fusion Advisory Committee included the following brief introduction and summary of findings and recommendations with regard to the qualitative benefits of international cooperation in fusion:

Fusion research and development have been characterized for several decades by active international cooperation and exchange of ideas. The U.S. fusion program has benefited significantly from work in other nations: the most striking example of this is the rapid U.S. development of the tokamak concept, originally investigated in the Soviet Union. Other nations' fusion programs have also benefited from U.S. research activities and concepts: for example, the stellarator approach, originally developed in the United States, is now actively pursued in Europe, Japan, and the Soviet Union. ...The INTOR studies provide an encouraging example of a major multinational advanced design activity....

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ENERGY ENGINEERING BOARD

Committee on International Cooperation in Magnetic Fusion
WORKSHOP ON INTERNATIONAL COOPERATION IN MAGNETIC FUSION
SECOND WORKSHOP

Auditorium, Building 543
Lawrence Livermore National Laboratory
Livermore, California
February 7-8, 1984

PURPOSE: To explore the opportunities, policies, and arrangements bearing on a qualitatively higher level of international cooperation in the development of magnetic fusion energy.

AGENDA

Organized by Daniel E. Simpson

Tuesday Morning, February 7

SESSION 1. INTRODUCTION. J. Gavin, Session Chairman

Purpose and Scope of the Workshop	Joseph Gavin
Status and Future Needs of the Fusion Program	Ronald Davidson
U.S. and Foreign Fusion Programs	Michael Roberts

SESSION 2. RELEVANT EXPERIENCE. R. Uhrig, Session Chairman

International Nuclear Energy Cooperation	Eric Beckjord
Joint Venture in the Design and Ground Testing of the Common Docking System for Apollo-Soyuz	Robert White
European Organization for Nuclear Research	Wolfgang Panofsky
International Energy Agency Experience	Donald Kerr
Computers and Semiconductors	John Manning

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FIGURE 2 Agenda for second workshop.

Tuesday Afternoon, February 7

SESSION 3. FUSION COOPERATION EXPERIENCE. R. Borchers, Session Chairman

Panel on U.S.-International Experience and
Lessons Learned in Fusion Cooperation

Panel Chairman:
R. Borchers
IMFOR: W. Stacey
Doublet III: J. Gilleland
KINS-II: C. Logan
FMIT: L. Trego

SESSION 4. TECHNICAL PROGRAM GOALS AND PERSPECTIVES ON INTERNATIONAL COOPERATION. D. Kerr, Session Chairman

Fusion Energy Potential, Technical Prospects,
and Goals

Kenneth Fowler

Panel Discussion on Programmatic Objectives,
Technical Needs, and Bases for
Cooperation in Plasma Physics, Reactor
Design and Technology, Materials, and
Engineering

Donald Kerr,
(Panel Chairman),
Ronald Davidson,
Kenneth Fowler, John
Sellers, Donald
Steiner

Wednesday Morning, February 8

SESSION 5. POLICIES ON INTERNATIONAL COOPERATION. J. Hendrie, Session Chairman

Panel Discussion on National Policy
Objectives, Domestic Considerations,
Public Interest and Acceptance,
and Long-Term Implications of
International Fusion Cooperation

Joseph Hendrie,
(Panel Chairman),
Vincent de Poix,
Melvin Gottlieb,
Richard Grant,
Charles Newstead,
Jan Roos, Gerald
Tape

SESSION 6. MANAGEMENT AND IMPLEMENTATION. M. Muntzing, Session Chairman

Organization and Implementation of
International Cooperative Agreements

Harold Bengelsdorf

Panel Discussion on Government and
Industry Roles, Constraints, and
Objectives for Implementing Programs of
International Cooperation

M. Muntzing, (Panel
Chairman), Eric
Beckjord, Harold
Bengelsdorf, Harvey
Brush, Dwain Spencer

FIGURE 2 Agenda for second workshop (continued).

SESSION 7. SUMMARY. D. Simpson, Session Chairman

Summary Conclusions and Remarks

Invited Participants

Fusion Laboratory Tour for Invited
ParticipantsCommittee Meeting: Key Conclusions and
Remarks.

Robert Uhrig, Donald
Kerr, Robert
Borchers, Joseph
Hendrie, Manning
Muntzing

Fusion Laboratory Tour for Committee

FIGURE 2 Agenda for second workshop (continued).

- o The U.S. fusion program and the development of fusion on a worldwide basis have been benefited significantly from the active exchange of information and ideas. International cooperation in fusion research should continue to receive strong emphasis in the U.S. program.
 - o The planning of national fusion facilities and programs has been guided to a considerable extent by a policy of avoiding international duplication and instead addressing complementary technical issues. This policy is both cost-effective and conducive to rapid technical development. It encourages broader coverage of options in the area of alternate concepts and allows larger steps to be taken in the mainline approaches within existing budgetary constraints.
 - o While maximum effective use should be made of research facilities abroad, to supplement U.S. capabilities, the overall priorities of the U.S. program should continue to emphasize the most promising reactor approaches.
 - o The international fusion effort will benefit from increased consultation in program planning and from the initiation of coordinated--or even jointly supported--research projects.
- Magnetic Fusion Advisory Committee, 1983

At the time of the workshop TFCX was identified as the critical near-term project in the U.S. program, which should not be delayed for reasons of international cooperation. A representative of the Office of Fusion Energy, U.S. Department of Energy (DOE), described the proposed TFCX as the "entry into the age of fusion power" but occurring in the "age of budget deficits." He said that the Secretary of Energy appeared sympathetic to TFCX, but required an answer to the basic question: Should this be a national U.S. project or should it be international?

One participant advocated the following direction for the U.S. programs, including major initiatives in both tokamak and mirror fusion:

- o The United States should position itself to lead an international effort in the 1990s by proceeding with TFCX.
- o The U.S. fusion program should position itself to meet an energy crisis by 1990 by proceeding with TFCX and also a mirror device, complementary to TFCX, to test power-system components.
- o The U.S. fusion programs should not rely on international cooperation now, but should be initiating steps toward expanded international cooperation, principally in technology development projects of moderate scope.

A number of workshop panelists emphasized the importance, to U.S. energy needs and technological leadership, of maintaining national control of program scope and direction, with opportunity for international partners to contribute but not to select just the most

attractive areas of research and development. No compelling technical reasons for international cooperation were established, in the sense that competence missing in the United States might be joined with such competence existing elsewhere to accomplish what otherwise could not be done. Nevertheless, technology development takes longer than expected and contributions can come from unexpected sources. Hence, fusion hardware development should be internationally coordinated--a step beyond past (successful) information and personnel exchange programs.

It was suggested that national programs might progress by "half-steps," with successive (national) projects "leapfrogging" their foreign predecessors. It was noted that this course is essentially competitive rather than cooperative in that at any particular moment one group will be "ahead."

The following dilemma faces the advocates of specific cooperative projects: on the one hand, the United States should establish its objectives and requirements for an activity before deciding what to offer for international participation; but, on the other hand, potential international partners should be regarded as equals, with full participation in setting cooperative program objectives as well as scope.

Because of the long lead time for major fusion facilities and the commitment of resources to them well in advance, it may be hard to influence the upcoming generation of large tokamaks. Thus it may remain to focus joint planning on the generation after next.

Examples of International Cooperation in Fusion and Other Technologies

A few specific examples of international cooperation in magnetic fusion were described. One, FMIT, was under serious discussion at the time of the workshop but is so far lacking agreement on joint participation. Other projects, already carried out, have been successful. Although these projects encountered difficulties and delays similar to cooperative efforts in other fields, there was general agreement that there were net benefits to the participating partners.

Successful international cooperation in other technologies were also reported. Most of these efforts have been of rather specific scope and purpose, and they include large projects as well as small ones. In most examples, the partners contributed specified tasks and hardware. Some examples, notably CERN, have succeeded when the international partners contributed specified cash payments to the international project. All speakers reported on difficulties and delays in communication and agreement. An international project is more difficult and time-consuming than a purely national effort--one speaker guessed by a factor of two.

Although there may be common themes in these prior examples there is no formula that guarantees success. Nevertheless, we can improve

the probability of success by adapting some of their best features and avoiding some of their pitfalls.

International Cooperation in Nuclear Fission

There are three levels where international cooperation in nuclear fission has been undertaken:

Information Exchanges Generally, information exchanges were successful if commercial consideration and licensing information were not involved. Overall, the United States has judged that it got less than it gave in dealing with other countries; but the exchanges have proceeded anyhow.

Small- to Medium-Sized Projects Often small or medium projects are part of a larger project that has been "sold" to other nations. These arrangements usually turn out to be beneficial to both parties in that they make more funds available for more work or they cut costs for the individual participants. Even so, the total cost of the project with multinational involvement is generally greater than if only a single nation is involved because of the time required for coordination. The successful programs have involved a clear program definition as well as a clearly defined scope for all the parties involved.

Large Projects Large projects are generally difficult to implement. They need a "lead" country, the classic example being the Super-Phenix, in which France is the lead partner and all other partners play lesser roles. The reason is that consensus management generally does not work in the technical field. The economic impacts on an individual country can be significant. The challenge of such international cooperation on large projects is to develop a strategy that can make the best of opportunities and overcome the difficulties.

The U.S.-USSR Apollo-Soyuz Docking Mission

There is little direct applicability to the fusion program of the international cooperation between the United States and the USSR in the Apollo-Soyuz spacecraft docking mission. The Apollo-Soyuz mission was a symbolic gesture of scientific cooperation to serve political objectives. Each party paid its own way. The overriding consideration was that both parties wanted the mission to succeed and they found a reason, namely, the potential rescue of astronauts, for proceeding. However, the following programmatic details involved in

this mission may be useful examples for future international cooperative efforts of a highly specific nature:

- o The method of operation was documented before the program began.
- o The project was managed by a technical project director.
- o Each working group was cochaired by joint chairpersons, one from each country.
- o Plans for the organization of the project established the documentation standards.
- o Interacting Equipment Documents documented the technical requirements and were signed by the joint chairpersons as well as the technical directors, and copies were sent to all official files and all groups.
- o Proposed changes were submitted on appropriate forms; there was no bypassing this procedure.
- o Material for meetings was sent one month in advance.
- o Telecommunications were sent between the parties every two weeks.
- o Translations were reverified after each meeting and differences were reconciled.
- o The parties agreed to use a common system of units, namely the International System of Units (commonly known by its French acronym SI), with only a couple of specific agreed-upon exceptions.

European Organization for Nuclear Research

The European Organization for Nuclear Research is a successful cooperative scientific organization, but its experience may not be relevant to fusion power development. The sole objective of CERN is the advancement of pure knowledge. There are few patent rights involved, there is no potential military or commercial application, and the transfer of "sensitive" technology usually is not a problem. Even so, along the way CERN has developed a number of tools that have been of economic value. Probably because of its success, CERN has eroded its original "base of the pyramid" concept for high-energy physics in Europe, in which each country was to provide its own "base" program with CERN functioning only as the apex of the pyramid. Instead, CERN attracted the best West European scientists and attracted most of the available money for large accelerator projects in the individual Member States. As a result, CERN's research tools are second to none in the world.

CERN is governed by its Council, which has two representatives from each country—one an administrative or political representative and the other a scientific specialist. The financing of the organization is through a percentage of gross national product of each country, with a cap of 25 percent of CERN's budget on the contributions of any country. The Council gives a stability to the organization, but it constitutes an inertia that is hard to overcome to take advantage of

dynamic developing situations. One especially important matter is that there are no preestablished "national rights" for members; that is, no country is guaranteed any particular position for its representative, any specified share of procurements, or any priority as to its projects within CERN.

The programs of CERN, the United States, and the USSR in high-energy physics have generally been complementary, or at least confirmatory in nature. Nevertheless, systematic international planning might have avoided some of the parallelisms, such as the similarity between the Brookhaven and the CERN Alternating Gradient Synchrotrons and the electron-positron storage rings of the Stanford Linear Accelerator Center and the German Electron Synchrotron, DESY. The International Committee on Future Accelerators tends to deal with the "generation-after-next" accelerators because the selection of the next accelerator is too sensitive to deal with in an international committee. In particular, the 20 teraelectronvolt x 20 teraelectronvolt proton-proton collider proposed by the United States may have to become an international project if it is to attract firm commitment.

International Energy Agency

Another example of international cooperation, the International Energy Agency, was formed in 1974 after the oil crisis of that period. The overriding purpose of IEA was to deal with oil shortages through allocations to the various nations. The cooperative research and development program of IEA in energy was initiated to make some of the other activities palatable for the nations involved.

At the present time, IEA is spending about \$500 million per year on 40 projects, down from a peak of 50 projects a couple of years ago. The governing board is made up of representatives at the ministerial level from the member countries. The U.S. representative is the Secretary of Energy. The management board is made up of representatives from the research and development establishments of the various member countries. For the United States this representative is the Director of the International Division of the Department of Energy. The Research and Development Committee of IEA, composed mostly of government research and development leaders from the participating nations, decides what research and development projects will be funded.

IEA specifically excludes any research and development in nuclear energy because that is covered by the Nuclear Energy Agency. Projects are carried out by various member countries and often involve bilateral or multilateral agreements among them. IEA serves the role of a research and development broker through the implementation of the IEA agreement. IEA is often involved in topical studies and technological assessment.

The IEA agreements specify the lead organization, and the countries involved in the reports provide a basis for overall management of the projects. The whole organization has fewer than 100 people, and it draws about one third of its support from the United States. IEA has been in operation for a number of years and has a good research and development record. However, the unfortunate experience with the Synthetic Refined Coal-2 project (commonly known as SRC-2) seriously hurt the image of the United States as a reliable partner in IEA work.

International Industrial Cooperation

There are a number of private companies operating internationally with experience that may be relevant as industry becomes more involved in fusion and as fusion ultimately approaches commercialization. International Business Machines Corporation (IBM) is such a company, and some of its policies were explained. IBM has manufacturing facilities and laboratories in 18 countries; each foreign laboratory is under the control of a counterpart U.S. laboratory. The corporation markets and services equipment in most countries of the world and tries to manufacture equipment in the region where it is used. IBM owns patents and leases the rights to these patents to the subsidiary laboratory (for instance, IBM-Japan). The firm also licenses patents to others under certain restricted circumstances. The corporation shares technology at the laboratory level and through publications, but it takes the necessary steps to protect its intellectual property rights. The corporation uses marketing agents (both governmental and nongovernmental) in foreign countries but it retains control of the technology. IBM will withdraw from any country that demands equity in a subsidiary or access to technology as a condition for operation.

Policy Considerations

There was a general acknowledgment that international cooperation in the development of magnetic fusion is certainly desirable and probably necessary. This view arose from a balancing of the probable gains and losses related to the policy considerations brought out in the workshop. However, there was a wide dispersion of views as to how extensive cooperation should be and to what extent it should influence U.S. programs as well as policies. This divergence clearly reflected different evaluations of the balance of gains and losses. For example, one person argued for international cooperation on the smaller steps, although reserving U.S. leadership for TFCX. Another argued that the United States should concentrate on only U.S.-funded projects until a decision point around 1990, when international projects would again be considered. The experts should do more homework and conduct more discussion on specific alternative research

and development plans in order to establish a clear strategy and objectives for international cooperation. One cannot make decisions until these points are resolved.

It was proposed that an implementation plan, more specific than the CPMP, is needed to guide the U.S. program. Such a plan would identify the goals and milestones needed to satisfy the national interest. The plan would guide the development of the industrial base for a magnetic fusion power program and would provide the means of evaluating the best opportunities for international cooperation. The plan should have a sound technological basis and should provide a clear statement of U.S. policies in some detail. Questions such as when we should aim to have a viable fusion power capability, what it will replace, and at what cost it is likely to be economical should be covered to the extent practical. One view was that there is no urgency for fusion power plants or fusion-fission hybrid facilities in the early 21st century. Thus, the appropriate research and development pace is consistent with emphasis on an international cooperative programs.

Workshop participants thought that some key decisions on budget and program direction would have to be made soon. For example, at the time of the workshop, proposals for TFCX were being formed. Accordingly, it seemed that decisions were needed on the technical scope of the machine and whether it is to be proposed solely a U.S. project or as a joint venture with others. Then, it seemed necessary to face hard questions of how to accommodate another major fusion machine within prospective budgets. It seemed unlikely that all of the current U.S. work can be continued if TFCX were to be built by the United States alone. Even with some of the costs shared by others, the U.S. part would be a major project.

International cooperation should enlarge the potential benefits; consequently, barriers and difficulties may diminish. Cooperative programs should be developed from open discussions of options for accomplishing mutual objectives. The cooperating parties need to have real contributions to offer and real benefits to obtain.

International collaboration, in the sense of working actively together as approximately equal partners in sizeable enterprises, as distinct from cooperation, in the sense of acting with others for mutual benefit on a small scale, is already vital to some U.S. industry. International cooperation in fusion should continue, with assurance of benefits to U.S. industry. Component and equipment industries should be close to the program because ultimately, the best developed industry will dominate. Program planning should consider how to hold industry attention for the long term. The policy panel of the workshop thought that national industrial policy issues, in connection with both national security and the capture of economic benefits, and technology transfer issues would become increasingly difficult as magnetic fusion development moves toward engineering tests and utilization technology development. U.S. magnetic fusion research, carried out in national laboratories, is as open to foreign businesses as to U.S. firms. This openness does not exist abroad,

where much research is considered proprietary. As magnetic fusion work leads toward commercial utilization, foreign firms are likely to have more government support in terms of sales assistance and financing terms than U.S. business, to judge by present practices in the nuclear, electronic, and military equipment fields.

Pressures to collaborate internationally on fusion matters are growing. The key motivating factor concerns finances resulting in cost-sharing concepts being pursued. Such international cooperation should not be deemed a threat to domestic programs but rather a reinforcement of national efforts. It was acknowledged, however, that it is often hard to get commitments for international activities for more than three to four years; but, even if so limited, international cooperation can be helpful to all participants.

The meetings following the Summit of Industrialized Nations at Versailles in 1982 and Williamsburg in 1983 offer an opportunity for international cooperation in magnetic fusion development that may not easily be created again. These meetings, under the thrust of the political initiative from the Heads of State, have determined that the IEA would provide the institutional basis for cooperative fusion program efforts. Specific programs have not yet been discussed, so the time is ripe for presenting initial proposals for cooperation, including joint projects. There was concern in the workshop that uncertainty and argument, in the U.S. fusion community, over the proper next steps might make it difficult to seize the opportunity offered by the Summit initiative.

One speaker held a pessimistic view of fusion as an electric power source. He suggested that the threshold for utility acceptance and use of fusion for power production would be much greater than was the threshold for fission power. Therefore, a much more complete scientific and engineering basis would be necessary to convince utilities to use fusion power. However, this objective could be achieved through international cooperation in science, engineering, safety reviews, and concept selection. Although the speaker thought there was no urgency for fusion power, he concluded that international cooperation would, when the time comes, greatly assist in the process of convincing electric utilities to adopt fusion power. The workshop was also reminded of the need for the eventual public acceptance of fusion and the role of public information about it.

From the point of view of national security, major fusion projects with the USSR are not considered feasible; a joint U.S.-EC-Japan framework may be best.

It was thought not constructive to negotiate too cleverly, to the disadvantage of a partner; such a policy will create a powerful competitor in time.

Implementation and Management Considerations

Various approaches to international cooperation are possible including bilateral, multinational, and international agreements. One

possibility is to use the IEA, which is established and has experience behind it, although some of its management concepts may be difficult to work with. Regardless of which approach is used, an essential ingredient is to have strong political support from the nation's leaders to set the tone for international cooperation. This solidarity is hard to achieve in the United States because of different points of view between the Administration and Congress. International cooperation involving the United States must take into account these difficulties and accommodate them so that the United States is not deemed to be an unreliable partner.

Technological developments usually take longer than projected and opinions change as to when major achievements have been reached. Therefore, it is difficult to hold the attention of industry for three to four decades, which may be the time required for fusion technology. This fact makes international cooperation difficult. Nevertheless, the participation of industry is an important aspect of fusion development, both as a matter of policy and in implementation of policy. Industry must determine how it can learn the technology as well as contribute it to the long time frames that are expected.

The relationships between an international board of directors and the project manager are crucial to the success of a project. If both are weak, then the international effort will be a disaster. A strong project manager and a weak board can work together successfully in good times. A strong board and a strong project manager may produce a success but at the same time have conflict potential. In the case of a strong board and a weak manager, the manager will have to go, and quickly. In any case the cooperative project must be managed at the technical level, although policies may be set at the political level.

Overall, the workshop panel members concluded that international cooperation in fusion can work and, in fact, has worked. Panel members encouraged further cooperative efforts. However, it is important to understand the views of potential partners so that agreement is reached through mutual understanding and discussions. For management and implementation of the program to be effective, there are several significant essentials:

- o The political process must be reliable and perceived to be so.
- o The national scientific community must have something to offer, and it will expect to get something in return.
- o Industry must be brought into the process at an early date, and problems such as the current utility structure must be considered from the beginning.

On the assumption that the United States will undertake more international cooperation in fusion, the fusion community should develop some basic principles for negotiating the agreements. Four points come to mind from the workshop discussions:

- o The basic motive is national self-interest, providing and receiving scientific and technical resources in order to achieve an earlier return on the resource expenditure than would otherwise be possible.
- o The agreements should provide for a workable system of management and decision making to get the project done on time.
- o The effort should call on U.S. industry as well as the fusion research community to the greatest extent possible.
- o The agreements should provide for licensing and technology transfer between the partners, such that U.S. industry will have access at a reasonable price to elements of technology provided by partners but not duplicated by U.S. industry under the agreements.

The formulation of a set of negotiating principles would be an appropriate task for a group of key people representing industry, laboratories, and universities to advise the Secretary of Energy. The work of this group should also be made available to the Director of the Office of Science and Technology Policy, officials of the Department of State, and others who will have a voice in what international cooperation is actually proposed and undertaken. The subject is important enough to receive top level attention.

APPENDIX C

SUMMARY OF TRIP TO JAPAN

Five members of the Committee on International Cooperation in Magnetic Fusion, of the Energy Engineering Board of the National Research Council-National Academy of Sciences, visited several magnetic fusion organizations in Japan from April 9-14, 1984. The group consisted of Joseph G. Gavin, Jr., chairman of the committee; Robert R. Borchers, Melvin B. Gottlieb, Weston M. Stacey, Jr., and Robert E. Uhrig, all members of the committee; and Dennis F. Miller and John M. Richardson, of the committee staff.

The group met in Tokyo with officials of the Science and Technology Agency; the Ministry of Education, Science and Culture; the Ministry of International Trade and Industry; the Japan Atomic Energy Research Institute; the Japan Atomic Industrial Forum; and the Nuclear Fusion Council of the Atomic Energy Commission. The group also conferred with officials at laboratories of the Japan Atomic Energy Research Institute at both Tokai and Naka-Machi, the Electrotechnical Laboratory and University of Tsukuba at Tsukuba, and the Institute of Plasma Physics of Nagoya University at Nagoya. Altogether, about 50 individuals participated in the various meetings.

The itinerary is shown in Figure 1.

PURPOSE AND ROLE

The purpose of the trip was to exchange preliminary views on the advantages and disadvantages of a greater level of international cooperation in magnetic fusion development. The committee wished to explore the technical needs and opportunities for international cooperation, the benefits that might flow to the cooperating countries, and the broad nature of the arrangements under which cooperation might be conducted. The primary goal was to assess the probability of cooperation on the "next big machine" and to find out how such international cooperation might be brought about.

The role of the travelers was to exchange views and to gather information as informally as possible. The committee had no authority to speak or act for the U.S. Government. The function of the committee was purely advisory.

NATIONAL RESEARCH COUNCIL
COMMISSION ON ENGINEERING AND TECHNICAL SYSTEMS
2301 Constitution Avenue N. Washington D C 20418

ENERGY ENGINEERING BOARD

JAPANESE ITINERARY FOR TRAVELERS FROM
COMMITTEE ON INTERNATIONAL COOPERATION IN MAGNETIC FUSION

Monday, April 9

Meeting with Mr. B. D. Hill and Mr. T. Okubo, Embassy of the United States, Tokyo

Meeting with Mr. H. Amemura, Deputy Director-General, Atomic Energy Bureau, Science and Technology Agency, Tokyo

Courtesy call on Mr. T. Fujinami, President, Japan Atomic Energy Research Institute (JAERI), followed by discussions with Drs. S. Mori, Y. Iso, and other key fusion officials, at JAERI headquarters, Tokyo

Tuesday, April 10

Meeting with Mr. I. Kawano, Director, Research-Aid Division, International Science Bureau, Ministry of Education, Science and Culture, Tokyo

Meeting with Dr. M. Kawata, Director-General, Agency of Industrial Science and Technology, Ministry of International Trade and Industry, Tokyo

Meeting with Members of Japan Atomic Industrial Forum Fusion Committee, representing Hitachi, Toshiba, Mitsubishi, and Tokyo Electric Power Company, at Tokai University Club, Tokyo

Wednesday, April 11

Briefing of JAERI Fusion Activities by Dr. K. Kudo, Deputy Director of Tokai Research Establishment

Visit to JFT-2M Facilities, Tokai

Visit to JAERI Fusion Research Center, Naka-Machi and briefing of the JT-60 Activities by Dr. Y. Iso, Director General

Tour of JT-60 Facilities

Reception hosted by JAERI, Mito

The National Research Council is the principal operating agency of the National Academy of Sciences and the National Academy of Engineering to serve government and other organizations

FIGURE 3 Japanese itinerary.

Thursday, April 12

Meeting with Dr. M. Sugiura, Chief, Energy Division,
Electrotechnical Laboratory, Tsukuba

Courtesy call on Dr. N. Fukuda, President, University of Tsukuba,
Tsukuba

Visit to Plasma Research Center, University of Tsukuba, Dr. S.
Miyoshi, Director, Tsukuba

Friday, April 13

Meeting with Dr. T. Uchida, Director, Plasma Physics Laboratory,
Nagoya University, Nagoya

Saturday, April 14

Meeting with Dr. H. Kakihana (Former Director, Plasma Physics
Laboratory, Nagoya University) and Dr. T. Miyajima, Chairman,
Nuclear Fusion Council, Japan Atomic Energy Commission, at JAERI
Headquarters, Tokyo

FIGURE 3 Japanese itinerary (continued).

SOME BASIC DIFFERENCES BETWEEN JAPAN AND THE UNITED STATES

Japan appeared to have a firmer, more consistent government energy policy deriving from its lack of natural resources. We were told that Japan intends to be successful with the light water reactor, the fast breeder reactor, and eventually the fusion reactor. The Japanese approach to the development of fusion contemplates only one device, the Fusion Experimental Reactor (FER), between JT-60 and a fusion power demonstration reactor (DEMO). By contrast, the United States contemplates two steps beyond its Tokamak Fusion Test Reactor (TFTR) before a demonstration reactor. The Japanese seem to have more direct industrial consultation and participation in the fusion program than the United States. Japan's electric utilities are more centralized and appear to be more financially sound than those of the United States. There are also well known basic cultural differences--language, numbers of people involved in decision making, and differences in security requirements.

There is a noteworthy incompatibility between the U.S. and Japanese approaches to large national research programs. The Japanese have an elaborate research coordinating structure within their government that brings to bear all aspects and views of a proposed research program. Decisions are reached by consensus, which involves compromise after all views are expressed. The process is called the "bottom-up" approach to decision making. As a result, there is great difficulty in changing a program, once approved. Rather, the emphasis then shifts to doing the agreed job as well as possible. In contrast, the United States uses a "top-down" approach, in which decisions are made by "top-level advisory committees," government administrators, and Congress with relatively little technical input. The U.S. emphasis is often on diversity of effort with a view to taking advantage of new developments.

This difference in approaches, in our opinion, need not be resolved; but it must be taken into account in all efforts to achieve cooperation with the Japanese. Both approaches have merit and every effort should be directed towards bringing the best of each approach to bear in the proposed joint efforts. Perhaps some middle ground between U.S. fluidity and Japanese rigidity would be best. Although it is clear that actual cooperation can come only after agreement at the highest levels, such action is only a necessary condition, not a sufficient one.

The program of university research conducted by the Ministry of Education, Science and Culture (Monbusho, after its Japanese acronym) seems less closely integrated with the program goals of the Japan Atomic Energy Research Institute (JAERI) and the Science and Technology Agency (STA) than the counterpart U.S. programs.

THE FUSION PROGRAM OF JAPAN

Large Facilities

The current Japanese program is based on a 1975 decision to build the tokamak device, JT-60, as a national project carrying the highest priority.

This policy was expanded in 1981 by a recommendation of the Nuclear Fusion Council, which was adopted by the Atomic Energy Commission in 1982. The program called for development work by JAERI under STA, leading toward a tokamak reactor, and basic research, including small-scale work on alternate approaches, at the universities and National Laboratories under Monbusho. The dividing lines between the two segments are not entirely clear.

The STA-JAERI program is focussed on developing the tokamak concept to the commercial stage in a sequence of experiments (JT-60 to FER to DEMO) and supporting technology development activities. At present, the primary emphasis in the program is on completion of JT-60 (Japan Atomic Energy Research Institute, 1982). The Naka site of JT-60 will also accommodate the FER. The purpose of FER is not only to demonstrate plasma ignition and burning, but also to provide a facility for testing and demonstrating fusion technology. The current JAERI plan is to construct FER on the Naka site, with a decision in the late 1980s, after JT-60 results are evaluated, to initiate construction. Officials at STA and the Science Council expressed a less firm commitment to FER, noting that the plan was made three years ago in a different financial climate.

The STA-JAERI program accounted in 1981 for over 77 percent of the budget. JT-60 expenditures in 1981 constituted 80 percent of the JAERI expenditures.

The JT-60 is now at about 85-percent completion, with first plasma expected in about one year and completion of the heating systems about a year later. The total cost will be over \$1 billion. All components are being thoroughly tested. Expenditures will be high but decreasing during 1985 and 1986, freeing up some funds for the development work scheduled for FER. The cost of FER is anticipated to be about \$2 billion plus about \$0.7 billion for development.

The general impression of the committee is that the Japanese have a strong and well planned applied research program in nuclear fusion--much stronger than many committee members expected to find. The JT-60 is clearly in the same "generation" as the TFTR at Princeton even though it will operate with hydrogen only. The "on time-within specification" construction of JT-60 is impressive. The back-up test and development facilities lend credibility to the optimism of the Japanese regarding their ability to design, build, and operate their next big test facility, FER.

Small Facilities

The Monbusho university program in basic research is built around a variety of small- to intermediate-scale experiments at several locations (Uchida, 1983). GAMMA-10 tandem mirror at Tsukuba, Heliotron E stellarator at Kyoto, and JIPPT tokamak and NBT bumpy torus at Nagoya are the largest. The Institute of Plasma Physics (IPP) at Nagoya has proposed to build a larger reacting plasma tokamak and is using this proposal as justification for acquiring a new site. Larger tandem mirror, heliotron, and laser fusion experiments have been proposed. It is generally acknowledged that only one of these will be approved because of financial constraints. The Monbusho program on alternative confinement concepts is active and productive. It is anticipated that an intermediate-sized device costing about \$200 million will be authorized within the next year or two. Apparently there is a tacit agreement that any new alternate concept magnetic confinement experiment will be located at IPP.

The Monbusho program accounted in 1981 for 22 percent of the budget, about a third of which was allocated to the inertial confinement program at Osaka University. None of these figures includes personnel costs, which are separately funded.

STA also supports a reversed-field pinch experiment at the Electrotechnical Laboratory (ETL). Most of these machines are more recent versions of similar U.S. devices. They benefit significantly from the U.S. experience, the availability of better instrumentation and computers, and the traditional Japanese attention to detail and quality workmanship. Some of these facilities have supercomputers (Fujitsu Falcom-100, which is comparable to the Cray-1 computer in the United States) available for analysis and data processing.

Particularly noteworthy among the development efforts is the work on superconducting coils conducted at JAERI and ETL.

Cooperation on research at the university and national-laboratory level (generally characterized as pure science) with unrestricted publication of results and international exchange of scientific information is a democratic tradition that has served both Japan and the United States well over the years. Exchanges of personnel between laboratories (especially postdoctoral fellows) have enhanced this traditional mode of international cooperation. While smaller-scale cooperation of this sort is useful, it was not the main thrust of our visit to Japan.

Key Groups and Attitudes in the Japanese Fusion Effort

JAERI clearly has the initiative in Japan's large-scale fusion development. The Nuclear Fusion Council of the Atomic Energy Commission seems supportive of the JAERI program. STA seems to be the government agency with the greatest responsibility for large-scale fusion.

Monbusho is not closely connected to the mainline effort. Its role in fusion is to support basic science and promising alternative fusion concepts in the universities. Officials at Monbusho disclaimed any responsibility for international collaboration in fusion development. No expansion in collaboration with the United States at the university level is foreseen because of flat budgets. As of April 1, 1984, the Monbusho fusion program was transferred from the Research Aid Division to the Applications Division; this transfer implies that fusion research is firmly established in Monbusho, comparable to other macrosciences, such as space science and high-energy physics. The process by which university fusion research results move toward application and commercialization was not clearly brought out.

The Ministry of International Trade and Industry (MITI) is watching fusion development with interest, but does not yet seem to be a dominant force.

A generally positive attitude about international cooperation was expressed by ministry officials (STA, Monbusho, and MITI), by fusion program leaders (JAERI, ETL, IPP, and University of Tsukuba) and by influential advisors (Nuclear Fusion Council), albeit with different emphasis:

- o STA officials seemed to be favorably disposed because of Japanese financial constraints.
- o Monbusho officials endorsed the principle but were apparently concerned about the impact on their budget.
- o MITI officials were noncommittal.
- o JAERI leaders were positive, probably because of their awareness of both financial constraints and technical benefits, but emphasized that cooperative activities must fit into their own program.
- o IPP leaders were noncommittal and were apparently concerned that major cooperation together with a constrained Japanese budget might adversely affect their program.
- o Nuclear Fusion Council members indicated that international cooperation must play a larger role than they had previously thought, presumably because of Japanese financial constraints.

The Japan Atomic Industrial Forum (JAIF) represents industry's interests in fusion (Japan Atomic Industrial Forum, 1983). Industry is actively involved as supplier of experimental equipment and exhibited great interest in acquiring and protecting fusion "know-how." Industry representatives of JAIF expressed a generally negative attitude on international cooperation, an attitude which seemed to be motivated primarily by their desire to supply the Japanese effort themselves. This group did not appear to be concerned that Japanese financial constraints may reduce the size of that effort or stretch out the period over which it is distributed. These representatives also indicated that Japan should not rely on any other country for the development of any technology that is critical. One

form of collaboration proposed by JAIF was to let Japanese vendors supply components for U.S. fusion experiments.

A concern about the reliability of the United States as a partner in international collaborative ventures was forcefully expressed by almost all groups. Volatility and instability in U.S. policy and inadequate planning and erratic changes in direction at the fusion program management level were cited as major concerns, under the polite term of "flexibility." It was made clear that the strongest possible implementing agreement, perhaps a treaty, would be necessary if the Japanese were to undertake a major collaboration with the United States.

In discussions with the JAERI program leaders a distinction was drawn between collaboration and cooperation. JAERI officials defined collaboration as each partner contributing about 50 percent (in a bilateral undertaking) and having a proportional voice in the decisions about objectives, design features, and so forth. Alternatively, cooperation was defined as one partner contributing about 10 percent towards the cost of the other partner's experiment in return for the opportunity to make some input to these decisions. Under this view, collaboration on a major project must start with joint formulation of the objectives, schedule, design features, and so forth. Under the other view, one country may appropriately ask another country to cooperate in a project which the former has defined, provided that the latter country is given the opportunity to make input to the final project definition.

The Japanese emphasized that a decision to cooperate on a particular activity must be developed "from the bottom up" in their system. This practice means that the activity must make technical and programmatic sense to everyone involved. As if to illustrate the point, our discussions about international collaboration went much better at the level of working scientists, who knew each other and were comfortable in mutual discussion, than at the level of ministry administrators, who were generally noncommittal.

If nuclear fusion were anywhere near the application stage, we doubt that there would be any Japanese interest at all in cooperating with the United States or anyone else. However, the practical or commercial application of nuclear fusion is decades away, and the total development costs may run into tens of billions of dollars. Under these circumstances it is hard for anyone to be against international cooperation in fusion research, especially since federal funding of nuclear fusion research seems to have stabilized in both the United States and Japan. Program administrators see international cooperation as a means of conserving scarce resources. Scientists see cooperation as a means of expanding or accelerating their program. In the real world, international cooperation may actually slow down a project and increase the total cost beyond what it would have been for one country.

All groups with which we spoke endorsed international collaboration in principle as desirable or necessary for technical progress, risk

sharing, and cost sharing. International collaboration is more important to Japan now than it was three years ago. Japan and the United States should think seriously about how to cause collaboration to come about. However, there may be a perception that the United States is interested in collaboration only because it cannot raise the needed funds alone. The converse perception may also be true about Japan. Specific proposals must be examined before specific commitments to international collaboration can be made. There was general agreement among the Japanese that it would be useful to start discussions in the near future regarding possible major cooperative efforts.

Achieving international collaboration will take time. Ideally, discussions would begin in 1985, after JT-60 operating results are available and when a better idea of the post-JT-60 machine has been formulated.

The ultimate commercialization goal need not preclude collaboration at the research and development level. There seemed to be no explicit indication of any national "race" to develop fusion, or strategies to run the race, or concern for the benefits of winning and the penalties of losing.

There seemed to be a preference for bilateral collaboration over multilateral because of the added complexity of the latter. Multilateral collaboration was thought to be harder on a big machine than on a technology test project. However, a case-by-case determination was thought necessary. There is reasonable possibility of planning a big (bilateral) effort with a satisfactory division of tasks. However, careful planning is needed because mistakes will be costly. It will be hard to include the Soviet Union.

COLLABORATION ON MAJOR FUSION PROJECTS

International cooperation must not impair the national programs. Extensive collaborative projects will have to satisfy the national programmatic objectives of the participating nations. Less extensive cooperative programs can be conducted at the margins of the national programs.

For purposes of discussing a specific possibility of collaboration, committee members introduced the subject of the Tokamak Fusion Core Experiment (TFCX), which, at the time of the trip, had been proposed in the United States. There seemed to be more real interest in collaborating on major fusion projects (like TFCX and FER) than on technological test facilities (like large coils, blankets, and tritium processing). The Japanese have set up cooperative programs with both the European Community and the United States that form important components of the Japanese planning. Japanese officials would certainly like to continue and to expand such activities, although there are some problems of implementation. An important area of discussion was whether this cooperation could be extended to collaboration on large devices, a particular example being TFCX. The

JAERI leaders believe that, even at a constant budget level, it might be possible to build FER on a unilateral basis. The FER would be a considerably more ambitious project than TFCX.

The Japanese technical leaders have a uniformly negative view about an experiment with only plasma physics objectives, such as some TFCX options, as an appropriate next-step experiment. They believe that engineering and technology objectives must have a major role in their next-step experiment. The view was expressed by JAERI program leaders that TFCX is seen as a U.S. solution to a U.S. situation--TFTR is operating and there is a need to move ahead towards the next step to maintain momentum, but the budget is constrained. Hence, TFCX, with the promise of early results, was seen as a good U.S. tactic. The Japanese believe that an experiment with more ambitious engineering and technology objectives would be appropriate for international collaboration. The JAERI program leaders made it clear that it would be inappropriate for the United States to ask Japan to collaborate on TFCX in the large-scale sense defined in the preceding section. They left open the possibility of cooperation, implying a more modest undertaking.

A possible joint TFCX-FER program emerged from discussions with JAERI leaders:

- o Japan would cooperate with the United States on TFCX by accepting U.S. design and contributing certain Japanese-made components. Japanese interest here is limited to component technologies relevant to FER. JAERI leaders would consider this work as part of their own technology development program. Although the magnitude of the Japanese contribution was not explicitly discussed, there was a distinct impression that a figure of 10 percent or less was meant.
- o The United States would reciprocate by cooperating, in the above sense, on FER.
- o Japan and the United States would cooperate on their respective technology development programs in support of FER.

The JAERI leaders feel that it would be possible for either side to obtain technical benefit from a collaborative project located in another country, but not without inconvenience. Experience in fabrication could be equitably shared by a balanced procurement program. Construction and operating experience could be obtained by long-term assignment of personnel.

A number of problem areas that would be associated with a collaborative project were identified--patents, different budget mechanisms and fiscal years, difficulty in controlling delays, personnel policies, and so forth.

Cost-sharing on TFCX at any appreciable level might impede the FER and thus delay Japanese progress toward a tokamak reactor unless there were some high-level agreement between Japan and the United States that would increase Japan's budget by the amount needed for its work on TFCX. It was also suggested at one point that international

collaboration on TFCX could well convert it to a more ambitious (and more expensive) project.

The idea put forth by the Japanese that their cooperation might take the form of delivering components for the next big U.S. fusion machine, provided that the experience gained would enhance their ability to manufacture components for their next big machine, is a clear advantage for them (and a potential disadvantage for the United States in the long run). This arrangement would allow the Japanese to develop the manufacturing capability that assures that they alone would possess the ability to advance the next generation of machines. In exchange, they would expect to receive the tritium-handling and other technology we have developed. Given the poor U.S. performance on the Large Coil Test Facility (LCTF), this proposal may be the best we can hope for in cooperative efforts.

Officials at MITI noted that collaboration can occur on smaller projects as well. Small-scale collaboration can be a precursor to large-scale.

COOPERATION ON BASIC RESEARCH, TECHNOLOGY, AND ALTERNATIVE CONFINEMENT CONCEPTS

The U.S.-Japan joint agreement for cooperation in fusion appears to be an adequate mechanism for establishing further cooperative activities in basic science and technology and in research on alternative confinement concepts.

One university group would appreciate a recommendation from the committee to increase collaboration at the university level. Cooperation under the joint agreement over the past few years appears, on the whole, to be viewed by the Japanese as successful. However, several complaints arose in the discussions:

- o The U.S. centers for some of the activities are located in areas that are difficult to reach and difficult of access because of security requirements (for example, Sandia National Laboratory at Albuquerque and Oak Ridge National Laboratory).
- o The United States did not make use of the Japanese bumpy-torus results in its evaluation of the concept.

Japan is engaged in research on a wide range of alternative confinement concepts (tandem mirror, heliotron-stellarator, reversed-field pinch, compact toroid, bumpy torus, and so forth). Cooperative planning of research and evaluation of results seems appropriate.

The Japanese scientists appear to have achieved a significant advance in superconducting magnets. Their progress in the LCTF program, sponsored by the International Energy Agency and administered by Oak Ridge National Laboratory, is impressive. Of the six participants, only the Japanese delivered their superconducting

magnet on schedule and thoroughly tested, thereby demonstrating its ability to meet specifications. As of the time of the trip, the German and Swiss coils were just being delivered almost a year late; and the three U.S.-manufactured coils have been a "disaster." The General Electric Company delivered its coil as its "best effort" and then recommended that it be scrapped. The Westinghouse and General Dynamics coils are delayed and are having manufacturing difficulties. With this kind of track record, one wonders that the Japanese would consider cooperating with the United States. Clearly U.S. industry has done an outstanding job on building equipment for the space program--one wonders why it cannot do equally well in the nuclear fusion program.

PROBABLE CONDITIONS ON COLLABORATION

There are several desirable principles for international collaboration:

- o No erosion of the strong national programs.
- o Mutual benefit.
- o Participating on an equal footing.
- o Assurance of continuity in the collaboration.
- o Acceleration of the national programs of the partners.
- o Overlap of program interest.
- o Achievement together of what is not achievable separately.
- o Full participation in planning right from the beginning; unilateral planning is not acceptable.
- o Full access to the technology that is developed.

Cost sharing alone is not a sufficient reason to collaborate. It is not clear what level of cost for a large machine would trigger collaboration, but \$1 billion was mentioned.

Japan must acquire fusion technology for its own use. The Japanese investment in collaboration must come back for the benefit of Japanese industry. Patents and know-how must be protected.

JOINT PLANNING

There seemed to be a dilemma in the Japanese position in that one could not discuss near-term candidates for cooperation or collaboration because that planning was already fixed. On the other hand, one could not discuss future candidates because that planning had not yet been done. The attitude was that no joint planning had really been done to date, but that there existed a possibility in the 1985-1988 time period for useful joint planning.

No existing organization, such as the International Energy Agency and the International Atomic Energy Agency, is really suitable to manage international collaboration. A new mechanism is needed, which may come out of the Versailles Summit process.

For managing a large facility, a "lead country" is needed. Putting decisions to "middle-level" bureaucrats is to be avoided; they are reluctant to take initiative.

Our final meeting, with representatives of the Nuclear Fusion Council of the Atomic Energy Commission, was particularly useful. That group was much more positive about fusion than we had been led to expect. The group also seemed positive about cooperation with the United States. In particular, it was said that starting some joint discussion now on TFCX would be good. One working group would be needed to discuss the best concept for TFCX. Another working group would be needed to discuss how to implement collaboration. It was suggested that the TFCX concept be addressed at the forthcoming May 1984 meeting of the U.S.-Japan Joint Coordinating Committee. Japan would participate in the early TFCX planning without any prior commitment to collaborate on construction. U.S. ideas on TFCX would be disclosed by preparing a report available to Japanese scientists. An intention was expressed to convey an interest in Japanese participation in early TFCX planning to an appropriate U.S. program leader.

There was a general consensus that discussions of options should continue on a long-term basis and that any large-scale collaboration would require considerable joint discussions and planning at a technical level as well as a firm commitment at a high level.

Certainly at the subministerial level of the agencies with which we spoke (STA, Monbusho, and MITI) there was an obvious (and well-prepared) reluctance to discuss any alternative that extended beyond the explicit policies expressed in the Atomic Energy Commission planning document of 1982.

SUMMARY IMPRESSIONS

The visiting members of the committee greatly impressed with the Japanese research efforts in nuclear fusion. The committee believes the United States has much to gain from cooperation with Japan. It seems timely to launch a serious well-organized joint planning effort. It is unlikely that any agreement toward future joint effort on a billion-dollar scale will result without such a base.

It is necessary to deal separately with the STA-JAERI complex and the Monbusho-university complex on cooperative or collaborative programs. Major next-step tokamak experiments and technology development are within the purview of the former agencies, while basic research and alternative confinement concept experiments come under the jurisdiction of the latter.

The existing U.S.-Japan cooperative agreement machinery is an adequate mechanism for definition and implementation of cooperation with the Monbusho-university programs.

A new mechanism is needed for definition and implementation of large-scale collaboration on next-step tokamak experiments and the

supporting technology development. A workshop, on the model of the International Tokamak Reactor (commonly known as INTOR), might meet periodically to define questions to be answered by each country in the interim between meetings, to discuss these answers, and to draft tentative agreements. Such a workshop could formulate a cooperative or collaborative program, guide its implementation, and monitor its progress. Participants in this workshop should be permanent, so as to establish continuity, and should have the stature and background to address the technical and administrative aspects.

A cooperative and collaborative program of the type suggested by the JAERI leaders would work to the long-term disadvantage of the United States because the Japanese would gain a disproportionate share of the valuable industrial experience relevant to a next-generation machine. However, the suggestion provides a starting point for working out a more favorable program, perhaps involving a collaboration (in the sense defined above) on an engineering test reactor (FER in the case of Japan). There were indications from the JAERI leaders that subsequent U.S. cooperation on a Japanese FER need not be an essential element of the collaboration.

Some attention must be paid to reconciling the Japanese "bottom-up" and the U.S. "top-down" decision-making processes. U.S. fusion program leaders might benefit by adopting, for their own programs, some aspects of the Japanese procedure of developing a consensus among the technical people involved. Such an approach would not only lead to better thought-out programs, but would also lead to a greater compatibility between the U.S. and Japanese technical program objectives. On the other hand, a necessary prerequisite to useful cooperation is agreement between the governments at the very top, which embraces cooperation as national policy.

APPENDIX D

SUMMARY OF TRIP TO EUROPE

Some of the members and staff of the Committee on International Cooperation in Magnetic Fusion, of the Energy Engineering Board of the National Research Council-National Academy of Sciences, met with a number of officials in Europe from May 20-25, 1984. The members were Joseph G. Gavin, Jr., chairman, Robert R. Borchers, Melvin B. Gottlieb, L. Manning Muntzing, and Daniel E. Simpson. In addition Dennis F. Miller and John M. Richardson, of the committee staff, accompanied the group.

Visits were made in Brussels to officials of (1) the Directorate General for Science, Research and Development of the Commission of the European Communities and (2) the U.S. Ambassador to the Commission of the European Communities. The group also met in Bonn with officials of the Federal Ministry for Research and Technology and the Max Planck Institute for Plasma Physics. In Paris the group conferred with officials of (1) the Institute for Basic Research of the Nuclear Studies Center (2) the International Energy Agency, and (3) the Embassy of the United States. The group then visited the Joint European Torus and Culham Laboratory of the United Kingdom Atomic Energy Authority, both near Abingdon, in Oxfordshire, England. Finally the group met with officials of the U.K. Atomic Energy Agency in London. The group interacted with about 40 individuals. The itinerary is given in Figure 1.

PRINCIPAL IMPRESSIONS

Before discussion at somewhat greater length, the principal impressions from the trip may be stated as follows:

- o The need to develop fusion energy is not equally urgent in Japan, the European Community (EC), and the United States, so that the incentives to cooperate are not equally strong.

NATIONAL RESEARCH COUNCIL
COMMISSION ON ENGINEERING AND TECHNICAL SYSTEMS

2101 Constitution Avenue Washington, D.C. 20418

ENERGY ENGINEERING BOARD

EUROPEAN ITINERARY FOR TRAVELERS FROM
COMMITTEE ON INTERNATIONAL COOPERATION IN MAGNETIC FUSION

Monday, May 21

Meeting with Prof. D. Palumbo, Directorate General for Science, Research, and Development, Commission of the European Communities, Brussels

Meeting with Honorable George S. Vest, United States Ambassador to the Commission of the European Communities, Brussels

Tuesday, May 22

Meeting with Dr. G. Lehr, Director General, Federal Ministry for Research and Technology, Bonn

Dinner hosted by Dr. K. Pinkau, Scientific Director, Max Planck Institute for Plasma Physics

Wednesday, May 23

Meeting with Dr. J. Horowitz, Director, Institute for Basic Research, Nuclear Studies Center, Fontenay-aux-Roses

Reception hosted by Dr. Thomas J. Wajda, U.S. Mission to the Organisation for Economic Cooperation and Development, and Dr. John P. Boright, Embassy of the United States, Paris

Thursday, May 24

Meeting with Dr. Eric Willis, Director, Office of Energy Research, Development, and Technology Applications, International Energy Agency, Paris

Meeting with Dr. H.-O. Wuster, Director of the Project, Joint European Torus, Abingdon

Dinner hosted by Drs. Wuster and Pease, Oxford

Friday, May 25

Meeting with Dr. R. S. Pease, Authority Programme Director for Fusion, Culham Laboratory, U.K. Atomic Energy Authority, Abingdon

Meeting with Mr. G. Stevens, Assistant Secretary, Atomic Energy Division, U. K. Department of Energy, London

The National Research Council is the principal operating agency of the National Academy of Sciences and the National Academy of Engineering to serve government and other organizations

FIGURE 4 European itinerary.

- o There is no long-run commitment to the integration of the EC and U.S. economies, so that the economic cooperation that impels cooperation in fusion within EC is absent between EC and the United States and in its stead is the ultimate prospect of economic competition.
- o The separate stakes in fusion held by the EC, Japan, and the United States may not easily be subordinated to a common effort seeking merely reduced research costs and earlier results.
- o Nevertheless, there is a pressure for cooperation from the Versailles Economic Summit and there is receptivity to it at the EC level.
- o The preservation of the identity of the EC program will be a likely constraint on wider international cooperation.
- o There is technical need and opportunity for cooperation in dovetailing and phasing large, world-class machines; but the desirability of technical diversity and the primacy of indigenous interests may preclude the early consolidation of planned EC, U.S., and Japanese machines into one common effort.
- o There is technical need and opportunity for cooperation on alternative concepts and generic technology, but such cooperation will probably be paced more by problems of implementation than by technical urgency.
- o The goals of the EC and the U.S. programs have not been articulated explicitly enough to formulate a specific plan for cooperation.
- o The United States must deal through EC rather than directly with any Member State.
- o The desirability of the United States as a partner is low because of perceived past unreliability in honoring commitments, ungenerous insistence on quid pro quo, efforts to attract financial support from EC, and tendencies to put forward its low priority projects as candidates for cooperation.
- o Nevertheless, joint planning for the period from 1988 onward is both possible and welcome.
- o Promising institutional forms for large cooperative projects go more toward the Joint European Torus model than toward the International Energy Agency model.

With regard to the fuller discussion that follows, recall that the European program is administered at the level of the Commission of the European Communities. Nevertheless, input to the Commission comes from the various Member States. Views at both levels need to be explored to provide a comprehensive picture. Thus there are often differences of viewpoint at the country level before reconciliation into a single Commission viewpoint.

THE FUSION PROGRAM OF THE EUROPEAN COMMUNITY

In the words of the most recent proposed five-year plan, for 1985-89,

...the Community Fusion Program is a long-term cooperative program embracing all the work carried out in the Member States in the field of controlled thermonuclear fusion. It is designed to lead in due course to the joint construction of prototype reactors with a view to their industrial production and marketing (emphasis added).

--Commission of the European Communities, 1984b

The EC program is about two-thirds of the size of the U.S. program, with the tokamak as the dominant approach. The overall program is staffed by about 3500 people, slightly over 1000 of whom are professionals. There is no mirror confinement and little inertial confinement work going on. Alternative confinement schemes being studied are the stellarator and the reversed-field pinch, together representing roughly 10 percent of the program. Almost all of the work is carried out in national laboratories rather than in universities.

Roughly half the support comes from the EC, the other half coming from separate national budgets of Member States.

The flagship of the program is the large Joint European Torus (JET) tokamak (about twice the volume of the Tokamak Fusion Test Reactor), installed adjacent to Culham Laboratory. JET is funded 80 percent by the EC and 20 percent by EC Member States individually. Budgets for the whole EC program are prepared and funded on a five-year basis and are reformulated after three years. The project is staffed by personnel drawn from all the European national laboratories, for example, Culham, Garching (Federal Republic of Germany), Fontenay (France), Frascati (Italy), and Jutphas (Netherlands). JET is now in the early operational phase. Successful completion of the facility represented a major success for European cooperation.

In addition to JET there are three large (\$40 million to \$100 million) tokamaks being built at Caderache, France (TORE SUPRA); Garching (ASDEX Upgrade); and Frascati (FTU). The TEXTOR device at Julich, Federal Republic of Germany, continues operation. Each of these four tokamaks is expected to stress a different aspect of tokamak physics while at the same time serving to maintain the national capability and national objectives of the participating EC countries.

The EC program is coordinated by the EC staff in Brussels, utilizing a "consultative committee" drawn from all member states. Each national program (or "Association") is managed by a steering committee drawn from both the EC and the particular association.

Future planning is centered on the Next European Torus (NET). The new tokamaks (previously mentioned) will probably go into operation in 1987, and JET is expected to attain operation with tritium in 1989. Assuming favorable results from these experiments, NET might move from

conceptual design to detailed engineering design by 1988 and into construction by 1991.

NET conceptual design studies are now under way at Garching with an EC team under the leadership of a former director of the Italian laboratory (NET Team, 1984). NET is viewed currently as an engineering test reactor. The current intent is that NET should provide all the data needed for a real, though perhaps not an economic, power-producing reactor. Other, less ambitious, options will also be studied. These studies have not yet developed to a point where they can be compared with U.S. designs and cost estimates, but such comparisons should be possible beginning later this year.

INCENTIVES AND CONSTRAINTS

Needs for Program Results

An obvious condition for successful international cooperation is that the needs of the participants for program results must be reasonably compatible. A French official noted that both the EC and the U.S. programs lacked clear enough objectives to provide high compatibility. Although the stated goal of the EC program--"construction of prototype reactors with a view to their industrial production and marketing"--seems straightforward, it omits much detail as to performance, schedules, and cost. U.S. goal statements are even less definite.

United Kingdom (U.K.) officials noted that the need for fusion perceived in that country was not strong, since the United Kingdom still exports energy. Fast breeder reactors were thought to be more promising and less costly. The point was made that materials research in connection with the fast breeder reactor is not "open." This remark is interpreted to be an indication of approaching commercial interest. Fusion work is needed mainly as an "insurance policy" and is not to be supported to the detriment of fission research. A German official held similar views. These views imply a descending level of incentive for fusion in Japan, the EC, and the United States and correspondingly different levels of effort.

There was little evidence of any French purpose or objective that will provide an incentive for more than incidental international cooperation in fusion beyond the EC program.

Economic Cooperation and Competition in the Long Term

The long-term economic benefits from fusion are thought to be great, but they certainly cannot be estimated accurately. All three of the world-class programs thus lack quantitative justification for their size and pace. The same long-term feature necessarily puts support for the program in the public sector. The utilities in Europe, as

eventual end users, are even more content than those in the United States to watch and wait without investing their own money.

Cooperative efforts on fusion within the EC are driven by the accepted reality of long-run economic cooperation. Thus natural obstacles to fusion cooperation have been overcome. There is faith that the ultimate economic benefits will be captured more or less equitably by all EC participants through normal diffusion within the European economy.

By contrast, there is no natural economic force that compels the EC and the United States to cooperate. The natural long-run competitive relationship will prevail and will make obstacles to fusion cooperation hard to overcome. The same observation holds between the EC and Japan and between the United States and Japan. No mechanism assures that the economic benefits will be captured equitably. More specifically, the fundamentally different treatment of government patent rights in Japan and the United States, for example, remains an unresolved obstacle.

One might expect that the separate stakes in fusion perceived by the EC, Japan, and the United States would tend to persist unaltered and not be easily subordinated to international cooperation.

The Influence of the Versailles Summit

The stated aim of the Summit Working Group in Controlled Thermonuclear Fusion is "to reach a consensus on the desirable strategy in fusion in order to facilitate early joint planning to coordinate individual development programs." Thus, by pushing for a world strategy to which all can agree, the meeting of the Summit of Industrialized Nations at Versailles in 1982, together with subsequent meetings, constitutes an external force toward cooperation. A German official was sympathetic with Summit guidance for joint planning of sequential (or phased) programs in the three world regions. U.K. officials conceded that high costs might compel a high-level mandate for cooperation, say, if the costs of NET reached the neighborhood of \$4 billion.

Character of the Program of the European Community

Fusion collaboration within the EC is viewed with much pride as a showpiece of research and development. JET is similarly viewed as the showpiece of fusion. There is significant desire by several of its participants, especially Germany, to maintain the self-sufficiency of the EC program. Germany supports cooperation as much for the psychological benefits of European cooperation as for actual progress in fusion. German officials were not anxious to broaden the scale of cooperation, since EC unity might be diminished and the German contribution might lose relative importance thereby.

A U.K. official had no view, without extensive staff analysis, as to whether the EC program should proceed alone or collaborate with

Japan or the United States. The same official, however, expressed reservations about any attempts to accelerate the EC program.

Thus preservation of the unity and coherence of the EC program, tailored as it has been to fit member-country needs, may be an important constraint on any broader-scale cooperative planning.

European Attitudes

A draft proposal for an EC Council decision (Commission of the European Communities, 1984b) states, "The Commission is convinced that international collaboration on fusion research and development is particularly desirable." At the political level of the Summit of Industrialized Nations, which includes the EC, science advisors to their respective governments have endorsed international scientific cooperation (Science, 1983; Science, 1984). A senior official of the EC fusion program, speaking from a position intermediate between the political and the management level, said that international cooperation should be an essential part of the fusion program, not just an incidental part. This official added that the EC is trying to extend collaboration beyond its frontiers. The motive may be anticipated budget problems associated with the high costs of future large devices. However, the three world-class programs would have to be brought into better coordination in order to enjoy fruitful cooperation on the next large step.

Attitudes in individual Member States differed somewhat from the above sentiments. Germans were largely opposed to large-scale cooperation with the United States, believing that the EC could probably pursue fusion development by itself. They perceived the United States as interested mainly in the one-way flow of cash from the EC to the U.S. program. French officials thought that collaboration was likely only on medium-sized projects and that, if the small-scale cooperation did not work, it would be all the harder to collaborate on large projects. French officials complained about lack of U.S. cooperation on the TORE SUPRA project. A U.K. official expressed his country's reluctance to become enmeshed in another large technology project like the Concorde supersonic transport. Another U.K. official noted that three-way collaboration would have such difficulties with design agreement, siting, procurement, and project management that it might not be workable in practice.

There are limits to large-scale cooperation, as evident in the second report of the so-called Beckurts Committee (Commission of the European Communities, 1984a), recently released. The Beckurts report recommends that expenditures "should be sufficient to keep Europe fully effective, competitive and thus in a strong position to negotiate information exchange and cooperation agreements with other partners." The report further recommends maintaining "a self-consistent European planning, avoiding too much reliance on decisions from other programmes." Overall, however, it would appear

that international collaboration is desired by the EC, although the extent and nature still are to be determined.

With regard to international cooperation, there are several different possibilities:

- o The EC, Japan, and the United States prefer to place primary reliance on their own programs in a self-sufficient way.
- o All three entities prefer to place primary reliance on their own programs, subject, however, to joint planning of scientific and technical developments.
- o Two or three of the entities desire to establish international relations that have a high degree of interdependence.

The attitude at the EC level seemed to be that the first possibility is not desired and that they are prepared to proceed at this time with the second, with the remote possibility of moving to the third sometime later if other matters are progressing well.

An International Energy Agency official cautioned that U.S. insistence on strict *quid pro quo* is counterproductive. The official also advised against completing a U.S. design for its proposed Tokamak Fusion Core Experiment (TFCX) and then asking for international financial support for such a design. This move would repeat the Fusion Materials Irradiation Test (FMIT) mistake.

No serious thought of large-scale collaboration with the USSR was evident.

TECHNICAL NEEDS AND OPPORTUNITIES

EC seems to have a coherent and unified technical program, with JET at the center and with complementary efforts filling gaps without duplication of effort. An extension to world cooperation first requires some consensus on the future world program, then improved collaboration on smaller projects, like FMIT, and then advances to larger projects. International agreements in force, such as TEXTOR, Large Coil Task (LCT), and Radiation Damage in Fusion Materials, lend encouragement to this view.

Large Machines

There was universal EC agreement on the JET to NET to demonstration reactor (DEMO) strategy. NET will be the basis for international cooperation on the next step. The aim of the 1985-1989 EC program is to establish the physics basis for NET, intended to be a burning reactor. Reactor-relevant technology is planned in conjunction with NET, but individuals disagree as to the relative importance of this feature.

German officials favored several world-class machines to provide the technical diversity necessary for achieving optimal solutions for a fusion reactor. German officials also felt that EC must have its

own machine to learn the technology of fusion. This view precludes the strategy of a single world machine. By contrast, the Summit Working Group recommends that parties "review the advantages and disadvantages of one single comprehensive project versus several interdependent, complementary, and partially sequential machines."

French officials were cool to the concept of TFCX. They perceived TFCX as more a matter of political expediency to maintain U.S. momentum than a matter of sound scientific investigation. Most of the Europeans believe that (1) the present TFCX designs are not sufficiently ambitious--for example, spending an additional 50 percent would more than double the value of the device--and (2) the insertion into the world scene of a device like TFCX might delay NET, which they regard as more fully committed. A "reasonable" share of TFCX costs (over \$100 million) would be extremely difficult for EC to commit. Even to help support FMIT would require the difficult process of requesting supplemental funding. Some of the European reluctance to express any interest in an ignition experiment like TFCX is certainly attributable to their waiting for the performance of JET to be understood better.

Technology Projects

The EC program seems in clear need of access to FMIT or equivalent, as well as other technology development work. However, the EC inclination is not to contribute to the construction costs of FMIT; and no funds are in the 1985-1989 budget for it. One the other hand, one French official did favor finding money for the operation of FMIT.

The opportunity to cooperate on TORE SUPRA is offered to the United States. TORE SUPRA may critically need U.S. support to maintain position in EC.

The future of the International Tokamak Reactor (commonly known as INTOR) study is pending, with U.K. and French officials not persuaded of the merit of further effort.

AGREEMENT AND IMPLEMENTATION

The Unity of the Program of the European Community

The EC program is extremely stable and long-term. It has provided significant benefits that would not have been realized otherwise, such as division of labor, concentration of effort, mobility of personnel, establishment of JET, and significant participation of European industry. These features are valued so much by the Member States that the continuation of the unity of the program will certainly be sought as a feature of wider international cooperation. Furthermore, all member countries would insist that wider cooperation be carried out only via the framework of EC, rather than by direct national agreements.

The national components of the EC program are highly valued now; but in time they may be supplanted by Commission activities only, just as the European Organization for Nuclear Research (commonly known by its original French acronym CERN) supplanted national activities in high-energy physics. Provided the EC member countries remain economically cooperative rather than competitive, this result may be acceptable.

Reliability of the United States as Partner

Officials of EC, IEA, France, Germany, and the United Kingdom stressed reliability, predictability, and avoidance of arbitrariness of style as essential to U.S. partnership in the implementation of cooperation. FMIT and LCT were cited as examples of prior U.S. unreliability in fusion, the Synthetic Refined Coal 2 (commonly known as SRC-2) project in energy, and the International Solar Polar Mission in space exploration. U.K. officials acknowledge a need for flexibility in program content, but opt for rigidity in carrying through projects, once agreed. A way to provide flexibility in programs is to collaborate over a broader base, so that tradeoffs are available. An IEA official advised the United States to stop putting forward its low priority projects for international cooperation.

While granting that some instances of the sort have occurred, one must still entertain the possibility that complaints about the reliability of the United States are being exploited as a bargaining position.

Institutional Suitability

The International Atomic Energy Agency (IAEA) is not a promising institutional home for collaboration because of USSR membership and because of the small scope and relevance of the IAEA fusion program.

The IEA has a record as a suitable institution for medium-sized projects, like LCT, but does not seem to have the infrastructure to manage large-scale collaboration, nor to be likely to acquire it.

A French official noted that, whatever the institutional entity, international agreement lends a project an extra degree of stability, protecting the project against budget fluctuations. The effect may be due to the perceived importance of the existence of an agreement.

The Europeans, by virtue of JET and the overall EC experience, seem better able to cope with the idea of international cooperation in a realistic way. Our discussions did not address how cooperation with the United States could be achieved without political and economic ties similar to those within the EC. No one seemed convinced that United Nations sponsorship or a "world science fund" could succeed. The issue of access to high technology information and know-how, not to mention technology with potential military applications, will need to be faced without an overall political and economic umbrella like

the EC. Such matters are not simple even with such an umbrella, as the breeder program demonstrates. Finally the issue of siting a large world-wide, or even a bilateral, endeavor will be an enormous problem.

The Joint European Torus as a Model of Project Management

The governance of JET (Commission of the European Communities, undated) seems to be a successful model, well worth study and imitation for implementation of other large international fusion projects. The undertaking enjoys great stability because of high-level commitments sought and obtained early in the program planning and budgeting process. The Director of the Project has broad authority and responsibility. He reports to and is subject to annual budget and program review by the JET Council. The Executive Subcommittee of the JET Council also approves procurement contract selection over 200,000 European Units of Account (ECU). The Scientific Subcommittee reviews in detail, and approves, the "project development plan." The JET management system has been intact and has worked effectively since project initiation in 1978.

JET does not supersede various national activities, because they are still needed to round out the program. By the time NET is undertaken these programs are expected to have run their courses, and more national activities may not be needed. A U.K. official suggested that NET may require new political agreements and organization beyond JET.

Participation in JET by an additional country, say the United States, would be possible upon approval by the Director of the Project, the JET Council, and the Council of the European Communities.

Joint Planning for Increased Cooperation

The United States might well consider fusion in a larger context of cooperation in science and technology, so as to match the EC science structure better. For example, fusion might be considered along with breeder reactors, space technology, computers, or biotechnology.

It was clearly stated, from JET experience, that joint multilateral effort involves interdependence, requires vigorous debate to produce an agreed program, and should result in a program of considerable stability.

Since the preponderant view is that international cooperation will be necessary but that it will take time and effort to achieve, it is generally agreed that it would be appropriate to start the discussions soon. Discussions should take place at two levels. First, there should be an effort to reach agreement on program goals since the Europeans do not understand current U.S. program goals. Second, there should be joint efforts at a technical level to see if agreement can be reached on the intermediate objectives and the possible timing of

the major devices and facilities that would be needed, as well as the critical criteria and decision points that would be involved in the go-ahead decisions.

There are new agreements in preparation that will keep the possibility of cooperation active at medium levels of effort, at least. However, what is lacking now is an international joint planning team to consider concepts for TFCX or equivalent, NET, and the Fusion Experimental Reactor proposed by Japan and how these machines might be modified to give optimum phased advances. German officials thought that joint planning would be feasible only for the period from 1988 onward, since plans until 1988 are rather firm. It was conceded that there is some flexibility in the EC program for NET, through joint planning, to take advantage of whatever physics results might be provided by TFCX. U.K. ministers would countenance some exploration of the possibility of bringing the world-class fusion programs together. A U.K. official noted it was still an open question of whether EC will go forward to NET and DEMO by itself, with only the incidental help of others, or will seek a truly joint undertaking with Japan or the United States. The former course has the advantage of making sure the technology is acquired by the EC, and the latter course has the advantage of probable savings in cost and time.

A JET official noted that an outside country could participate in a large EC project, like NET, say, without participating in all the rest of the EC program. A U.K. official would like to see as much collaboration as possible on smaller projects to gain experience and confidence.

Site selection for NET will remain a difficult issue, as judged by prior insistence to exclude the site of JET and by the competition among Cadarache, Garching, and Ispra as candidate sites.

It seems that, given a strong and well presented U.S. initiative, an international agreement on joint program planning and collaboration at intermediate project sizes could be achieved. However, there would be substantial obstacles, problems, and friction in reaching agreement and in implementation. The question is: Is it worth it?

APPENDIX E

PRINCIPAL PARTICIPANTS IN DOMESTIC WORKSHOPS AND FOREIGN MEETINGS

FIRST WORKSHOP ON INTERNATIONAL COOPERATION IN MAGNETIC FUSION

CHARLES C. BAKER, Argonne National Laboratory, Argonne, Illinois
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RICHARD D. DELAUER, U. S. Department of Defense, Washington, D.C.
JOHN DUGAN, U. S. House of Representatives, Washington, D.C.
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DAVID LEIVE, International Telecommunications Satellite Organization,
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JOHN N. MOORE, University of Virginia, Charlottesville, Virginia
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SECOND WORKSHOP ON INTERNATIONAL COOPERATION IN MAGNETIC FUSION

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 VINCENT DE POIX, Teledyne Wah Chang, Albany, Oregon
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 DONALD STEINER, Rensselaer Polytechnic Institute, Troy, New York
 GERALD F. TAPE, Associated Universities, Incorporated, Washington, D.C.
 C. LAMAR TREGO, Westinghouse Hanford Company, Richland, Washington
 ROBERT D. WHITE, NASA Johnson Space Flight Center, Houston, Texas

MEETINGS IN JAPAN

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 H. AMEMURA, Science and Technology Agency, Tokyo
 TSUNEO FUJINAMI, Japan Atomic Energy Research Institute, Tokyo
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 NOBUYUKI FUKUDA, University of Tsukuba, Ibaraki-Ken
 HIDEO IKEGAMI, Nagoya University, Nagoya
 HIDATAKE KAKIHANA, Atomic Energy Commission, Tokyo
 M. KAWAGUCHI, Science and Technology Agency, Tokyo
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 MICHIO KAWATA, Ministry of International Trade and Industry, Tokyo
 K. KUSAHARA, Ministry of Education, Science and Culture, Tokyo
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MASARU SUGIURA, Electrotechnical Laboratory, Ibaraki
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 M. WADA, Science and Technology Agency, Tokyo
 KENZO YAMAMOTO, Japan Atomic Industrial Forum, Incorporated, Tokyo
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MEETINGS IN EUROPE

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 ROY BICKERTSON, JET Joint Undertaking, Abingdon, Oxfordshire, England
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 F. DIERKENS, UNIPED, Brussels, Belgium
 P. FASELLA, Commission of the European Communities, Brussels, Belgium
 UMBERTO FINZI, Commission of the European Communities, Brussels,
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 MICK LOMER, Culham Laboratory, Abingdon, Oxfordshire, England
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 THOMAS J. WAJDA, United States Mission to the Organisation for Economic
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GLOSSARY

- ASDEX: Axisymmetric Divertor Experiment, in the Federal Republic of Germany.
- CERN: European Organization for Nuclear Research (after its original French acronym).
- CPMP: Comprehensive Program Management Plan.
- DEMO: Fusion Power Demonstration Reactor.
- Divertor: A magnetic field configuration that directs the trajectories of impurity atoms out of the fusion plasma.
- DOE: U. S. Department of Energy.
- D-III: Doublet III.
- D-T: Deuterium-tritium fuel cycle.
- EBT: Elmo Bumpy Torus, an alternative fusion reactor concept.
- EC: European Community.
- Electron cyclotron resonance heating: Technique of radio-frequency plasma heating that puts energy directly into the plasma's electrons.
- ECU: European Unit of Account.
- ETR: Engineering Test Reactor.
- ETL: Electrotechnical Laboratory, Japan.
- EURATOM: European Atomic Energy Community.
- FED: Fusion Engineering Device.
- FER: Fusion Experimental Reactor, Japan.

FMIT: Fusion Materials Irradiation Test.

FTU: Tokamak planned for 1987 operation at Frascati, Italy.

IAEA: International Atomic Energy Agency.

IBM: International Business Machines Corporation.

IEA: International Energy Agency.

Impurities: Atoms heavier than the fusion fuel, the presence of which in the fuel volume can remove by radiation the energy needed to sustain ignition.

INTELSAT: International Telecommunications Satellite Organization.

INTOR: International Tokamak Reactor.

IPP: Institute for Plasma Physics, Nagoya University, Japan.

JAERI: Japan Atomic Energy Research Institute.

JET: Joint European Torus, at the JET Joint Undertaking, near Abindgon, in Oxfordshire, England.

JIPPT: Stellarator hybrid, Japan.

JT-60: Tokamak under construction at the Japan Atomic Energy Research Institute.

LCT: Large Coil Task.

LCTF: Large Coil Test Facility, at the Oak Ridge National Laboratory.

LLNL: Lawrence Livermore National Laboratory.

Magnetic confinement: Any scheme that seeks to isolate a hot (fusion) plasma from its surroundings by using magnetic lines of force to direct the charged particles.

MFAC: Magnetic Fusion Advisory Committee, advisory to the Office of Fusion Energy, U. S. Department of Energy.

MFTF: Mirror Fusion Test Facility, Lawrence Livermore National Laboratory.

MITI: Ministry of International Trade and Industry, Japan.

Monbusho: Ministry of Education, Science and Culture, Japan, after its Japanese acronym.

Neutral-beam injection: Heating of contained plasma toward ignition by injection of beams of energetic (typically greater than 100 thousand electronvolt) neutral atoms, which can cross the magnetic lines of force but which are later ionized in the contained plasma, thus being themselves contained.

NET: Next European Torus.

ORNL: Oak Ridge National Laboratory.

OTR: A next-generation engineering test reactor, USSR.

Plasma: A gas comprising some large fraction of charged particles.

Radio-frequency heating: The application of radio-frequency electromagnetic power (loosely speaking--microwave power is included under this rubric), which, when in resonance with the gyromagnetic properties of the plasma, can be used to deposit energy in it, thus heating toward ignition.

Reversed-field pinch: An alternative magnetic confinement concept under investigation in several countries.

RTNS-II: Rotating Target Neutron Source II.

STA: Science and Technology Agency, Japan.

Stellarator: A toroidal device (pioneered in the United States) wherein plasma equilibrium and stability are achieved by externally imposed magnetic fields rather than by toroidal currents within the plasma, as in the tokamak.

Super-Phenix: A 1200-megawatt (electric) fast breeder reactor, in France.

Tandem mirror: A magnetic containment device in which two mirror machines close the ends of a simple magnetic solenoid.

TEXTOR: A plasma technology experiment built by the Federal Republic of Germany.

TFCX: Tokamak Fusion Core Experiment, proposed in the United States.

TFTR: Tokamak Fusion Test Reactor, Plasma Physics Laboratory, Princeton University.

TORUS SUPRA: Tokamak being built at Caderache, France.

Tokamak: A magnetic containment device in which the magnetic lines of force are closed on themselves in the shape of a torus, with a large current flowing through the plasma.

Toroidal: The azimuthal direction, about the central axis, within a toroidal containment device.

U.K.: United Kingdom.